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Examining Augmented Reality in Middle Schools through a Review of Studies on Augmented Reality in Education

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Examining Augmented Reality in Middle Schools through a Review of Studies on Augmented Reality in Education

by

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Report

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Abstract

Examining Augmented Reality in Middle Schools through a Review of Studies on Augmented Reality in Education

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The University of Texas at Austin, 2020

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Although augmented reality (AR) is considered a promising technology in the field of education, many educators are still having trouble distinguishing between AR and virtual reality. Therefore, this report aims to present and refine the understanding of AR technology in middle school-level education based on existing studies published in the last three years. A total of eighteen academic journal articles were reviewed to obtain a comprehensive view of the definitions, types, features, advantages, limitations, and integration methods of AR in middle schools. According to Azuma (1997), AR is a technology that enhances one's sense of reality by enabling the coexistence and simultaneous interaction of digital information and the real world. The most commonly used types of AR today are marker/vision-based and location-based. Based on the reviewed studies, eight features, five advantages, and six limitations of AR technology

are identified. In addition, the ways in which AR technology has been integrated into middle school classrooms are described.

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Introduction

According to Azuma (1997), AR refers to a technology that enhances one's sense of reality by enabling the coexistence and simultaneous interaction of digital information and the real world. Today, augmented reality (AR) is considered a promising technology for education, and it has been investigated for almost two decades in diverse educational fields (Akçayır & Akçayır, 2017). However, many people, including educators, still confuse AR with virtual reality (VR). Moreover, they may not be knowledgeable of AR technology in education or its features, advantages, and limitations. Therefore, the following report aims to present information about AR technology in middle-school-level education based on existing studies published in the last three years. Specifically, it will discuss the definitions, types, features, advantages, limitations, and integration methods of AR in middle school.

The report synthesizes 18 peer-reviewed articles identified by searching the educational databases Education Source, ERIC, and APA PsycINFO using the keywords "augmented reality" AND "middle school" OR "junior high or 6th or 7th or 8th or secondary." A total of 115 articles were identified with these keywords. However, the group of articles was narrowed by applying some criteria. First, only scholarly peer-reviewed journals published from 2017 to 2020 were included. Additionally, the article should be written in English and focus only on AR, excluding similar concepts such as VR, augmented virtuality, simulation, and mixed reality. The age range of the targeted students was also limited to middle school or junior high school (i.e., sixth to ninth graders), excluding students from first to fifth grade and tenth to twelfth grade. This age range was chosen because this is a critical period for students. According to Piaget's theory of cognitive development, these students are in the concrete operational stage, and thus they are not fully proficient in processing abstract and intangible concepts, such as gravity, spectra, and radio waves (Oléron, Gréco, Piaget, & Inhelder, 2014). Around twelve years of age, students transition to the formal operation stage, in which they can engage in conceptual thinking and sophisticated reasoning. This report aimed to examine how AR influences students in the critical period. Lastly, articles about AR deployed in special education were excluded. After applying these criteria, the final sample consisted of 18 articles.

This report consists of two parts. The first is a synthesis of the 18 peer-reviewed articles, and the second is an article that will be submitted to the practitioner journal of the Association of Texas Professional Educators (ATPE). The practitioner report aims to explain AR to teachers and inspire them to apply classroom practices that involve AR. The content of the article is based on the 18 peer-reviewed journals.

Part I: A Synthesis

Definition of Augmented Reality

According to Azuma (1997), AR refers to a technology that enhances the sense of reality by enabling the coexistence and simultaneous interaction of digital information and the real world. Virtual applications in AR are constructed of physical objects (Karagozlu, Kosarenko, Efimova, & Zubov, 2019). Thus, as the surrounding physical environment changes, the virtual applications change as well. Pokémon GO is a good example of an AR mobile game. As players wander around in the real, physical world with their cell phone, they encounter a Pokémon as a virtual object in an app that simultaneously projects real, physical objects on the screen (see Figure 1).

Figure 1. Pokémon GO (iStock, 2016).[1]

[1] Pokémon Go. [Image]. (2016).

Today, AR is considered a promising technology for education, and it has been investigated for almost two decades in diverse educational fields with different variables (Akçayır & Akçayır, 2017). Intensive studies have been conducted on AR, and it has been employed in many places for educational purposes. However, there are still many educators, such as teachers in schools, who misunderstand AR as a type of VR, which is a technology that offers a three-dimensional (3D) virtual environment and simultaneous interaction between the user's movements and the environment (Hartman & Bertoline, 2005). One of the biggest differences between AR and VR is that AR provides 3D environments that combine real and virtual objects, whereas VR offers fully virtual 3D environments. As shown in Figure 2, when using VR, since a person is isolated from the physical environment by wearing a head-mounted device that covers their eyes, the only things they can view are virtual objects.

Figure 2. An experience of VR with a VR headset (MediWorldME, 2020)[2].

[2] OSSO VR: Virtual reality training surgical platform. [Image].

Common Types of Augmented Reality

There are several types of AR, but there is no one system of categorization. Some people categorize location-based AR as a type of markerless AR, whereas others classify location-based AR as another type of AR itself. Controversially, there is no unified terminology for different types of AR, including marker-based AR (Sirakaya & Çakmak, 2018a), image-based AR (Ibáñez, Uriarte Portillo, Zatarain Cabada, & Barrón, 2020), vision-based AR (Tomara & Gouscos, 2019), and the place-independent approach to AR simulation (Dunleavy, Dede, & Mitchell, 2009).

The most commonly used types of AR in the 18 articles selected for synthesis are marker/vision-based and location-based, which serve as the basis for the classification used in this paper. Marker/vision-based AR requires one to scan physical images or objects (e.g., markers, quick response [QR] codes, real objects, body movements) in order to trigger superimposed virtual content. Location-based AR produces augmented digital information as a user with a device physically moves to a specific geo-location.

Marker/Vision-Based Augmented Reality

In marker/vision-based AR, as shown in Figures 3 and 4, the camera on a mobile device identifies objects or specially designed markers (e.g., temple markers, barcode markers, circular markers, QR codes) in the world and processes the resulting images. Then, the mobile app projects virtual 3D information on these objects or markers in real time (Karagozlu et al., 2019). In other words, when a user employs marker/vision-based AR, they will see a virtual object or objects by scanning a specially designed image or marker, which triggers an augmented experience. This type of AR is utilized to, for example, teach about the structure and function of the human heart in anatomy class (Chen, Zhang, Luczak, Smith, & Burch, 2019). When students scan a QR code provided by an instructor with a mobile device, such as a smartphone or tablet, an animated virtual human heart is displayed on the device's screen. Students can manipulate and interact the virtual heart in real time by touching, zooming in/out, or dragging/pulling the object on their device's screen. Thus, AR enables them to visualize and concretize how the right and left atria and ventricles work and how blood flows in the human heart.

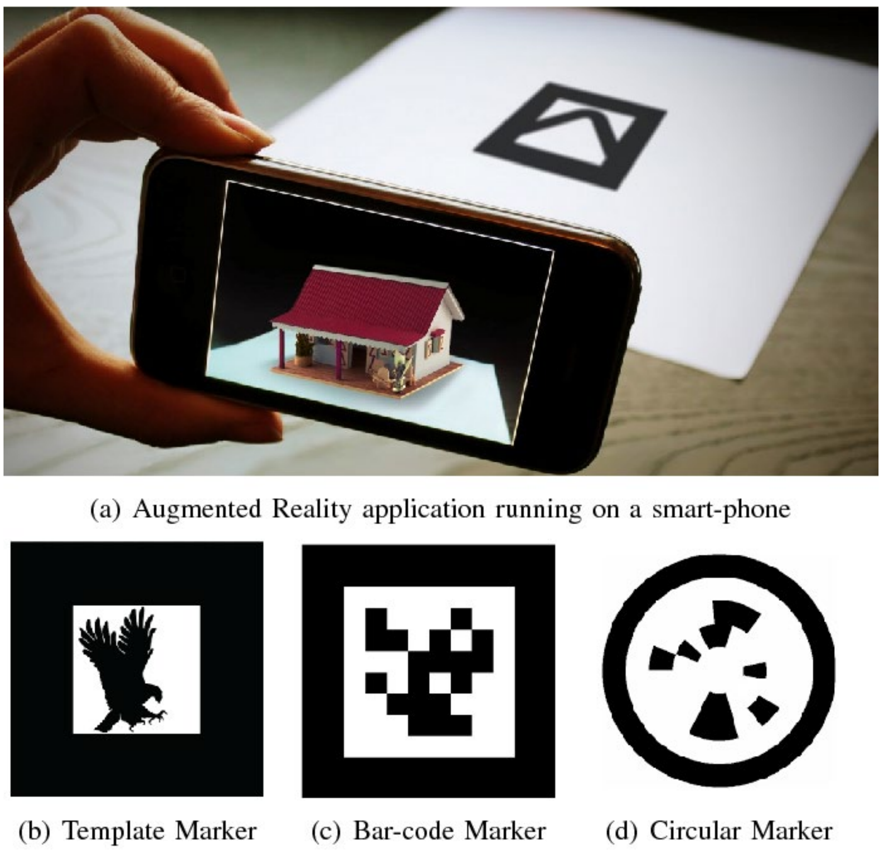


Figure 3. Types of markers for marker/vision-based AR (Nguyen & Yeap, 2016, p. 1).

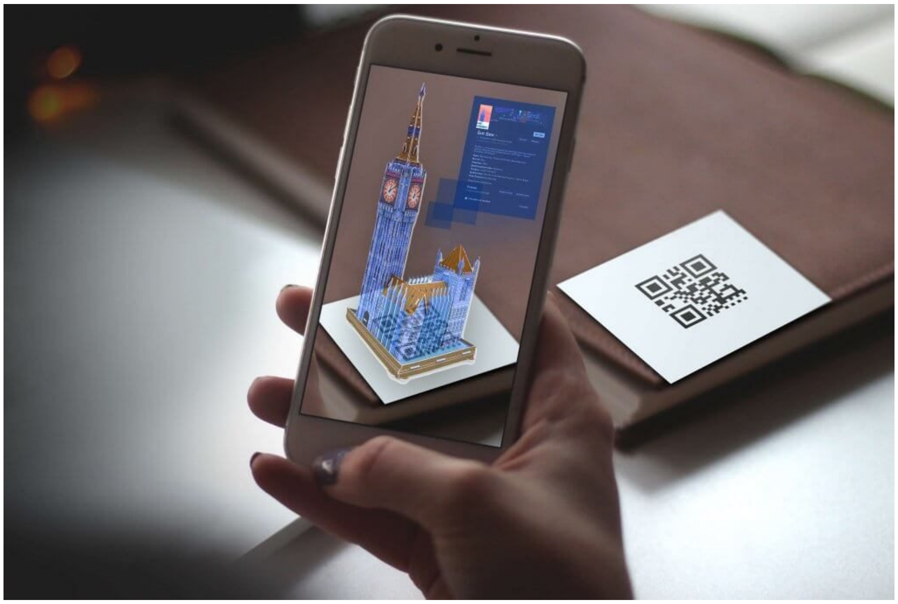


Figure 4. QR code (McDermott, 2018).

Location-Based Augmented Reality

Location-based learning has different characteristics and ways of operating than marker-based AR. As a user wanders around a physical area with a global positioning system (GPS)-enabled smartphone or similar mobile device, location data are tracked in a mobile app and matched to pre-programmed information linked to specific locations (Karagozlu et al., 2019). When the user reaches a specific location matched with existing information, a pre-programmed virtual 3D object and/or information will be displayed in the app along with projected physical objects and environments around the user. For example, as shown in Figure 5, reviews and ratings of a coffee shop could be displayed in a specific location. In addition, in an AR-based game, when a player reaches a specific location, a virtual character could pop up, providing the user with information and helping them to move forward. A familiar example of a location-based AR game is Pokémon GO, in which Pokémon are pre-programmed and geographically mapped to show up when players' mobile device locations match pre-determined locations. As another example, the location-based AR application Mystery at the Lake allows students to learn scientific concepts related to the aquatic ecosystem, such as the food chain, eutrophication, and bioaccumulation (see Figure 6; Georgiou & Kyza, 2018). In this application, a student is given a mission to address the mysterious decline of the lake's mallard ducks. During the learning activity, the student serves as an investigator, wandering around Bishop Lake in Cyprus with a tablet in order to obtain information. As shown in Figure 6, when a learner moves around and is not close enough to the location that triggers a virtual object, they can view a scene of the lake with a map. However, when the learner reaches a predetermined spot, related videos and text-based information appear on the mobile device's screen. Based on the information the students collect, they analyze the data, hypothesize about the reason for the mysterious decline, and make a conclusion. By engaging in the learning activity and solving the problem, they can gain much knowledge about the ecosystem while being physically present in it.

Figure 5. Examples of location-based AR (BSETec, n.d.).[3]

[3] Location based augmented reality. [Image]. (n.d.).

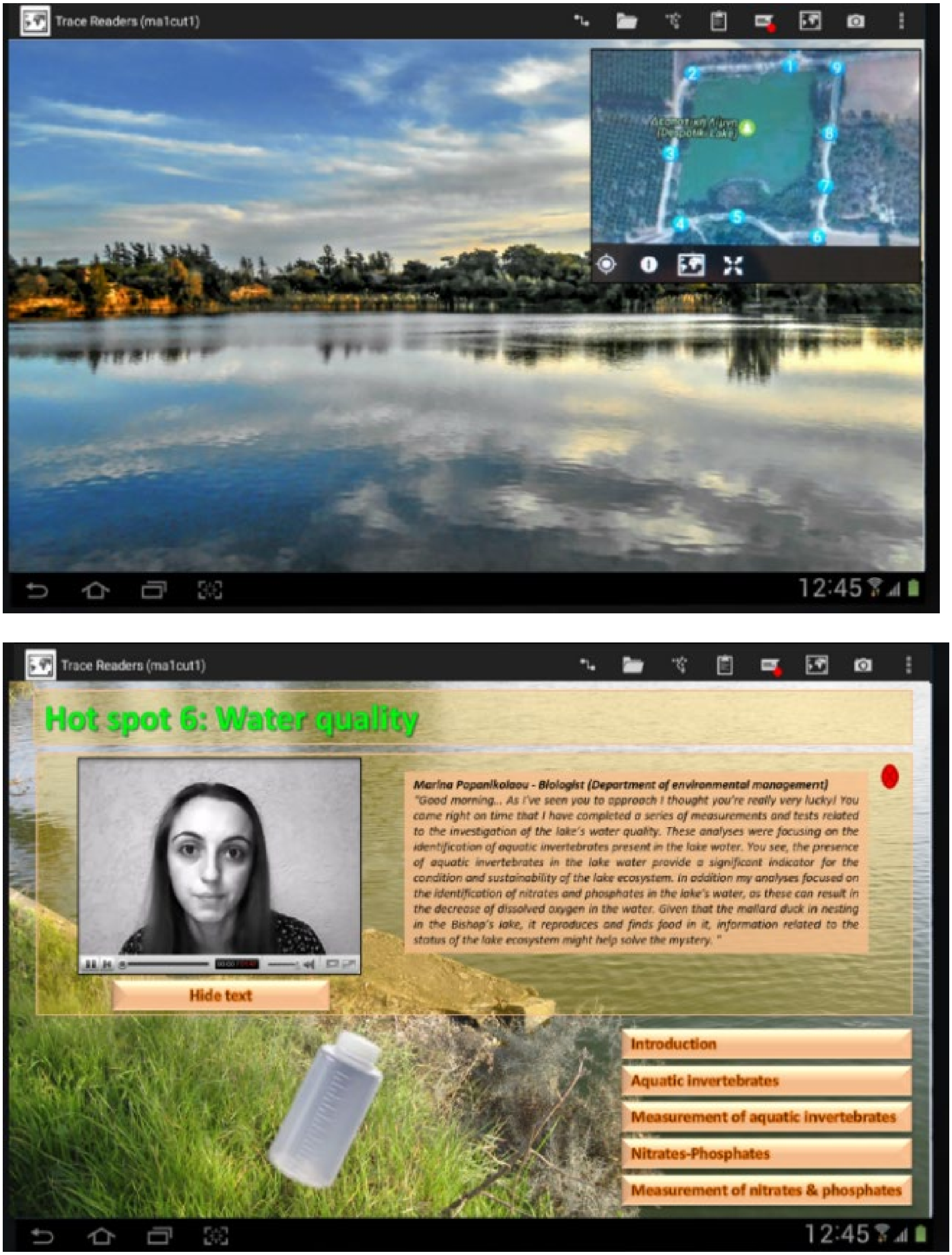


Figure 6. Mystery at the Lake (Georgiou & Kyza, 2018).

Common Features of Augmented Reality

Several features of AR are commonly mentioned in research studies involving AR (see Figure 7). The following section describes the common features of AR revealed through the review of the studies.

Real-Time Interaction/Manipulation

Among the 11 features included in the graph (see Figure 7), real-time interaction/manipulation was mentioned in 17 articles. This is one of the most prominent features of AR, as it allows a user to simultaneously interact with objects superimposed on real-world settings. Thus, reaction of the virtual objects in AR concurrently changes, as the learner moves around, drags, or zooms in/out on virtual objects (Xiao, Cai, Li, & Qiao, 2018). For instance, in Mystery at the Lake (Georgiou & Kyza, 2018), when a student is near to Bishop Lake, they can view textual information or a video related to their specific location, such as the water quality and creatures living in the lake. If the player leaves the location, the information will disappear. In another example, Virtuali-Tee simulates human organs, which can be manipulated in the application (see Figures 8 and 9). As a learner touches or zooms in on the virtual heart, small intestine, or lung, they can view each organ's name and see how it works in real time. The application can also measure the user's own heart rate in real time and show a virtual heart pumping at the same speed. In both examples, the learner receives real-time feedback as they explore new concepts and tests their knowledge by manipulating simulated objects via AR technology, which may enhance their comprehension of the subject matter (Bhagat, Liou, Michael Spector, & Chang, 2019).

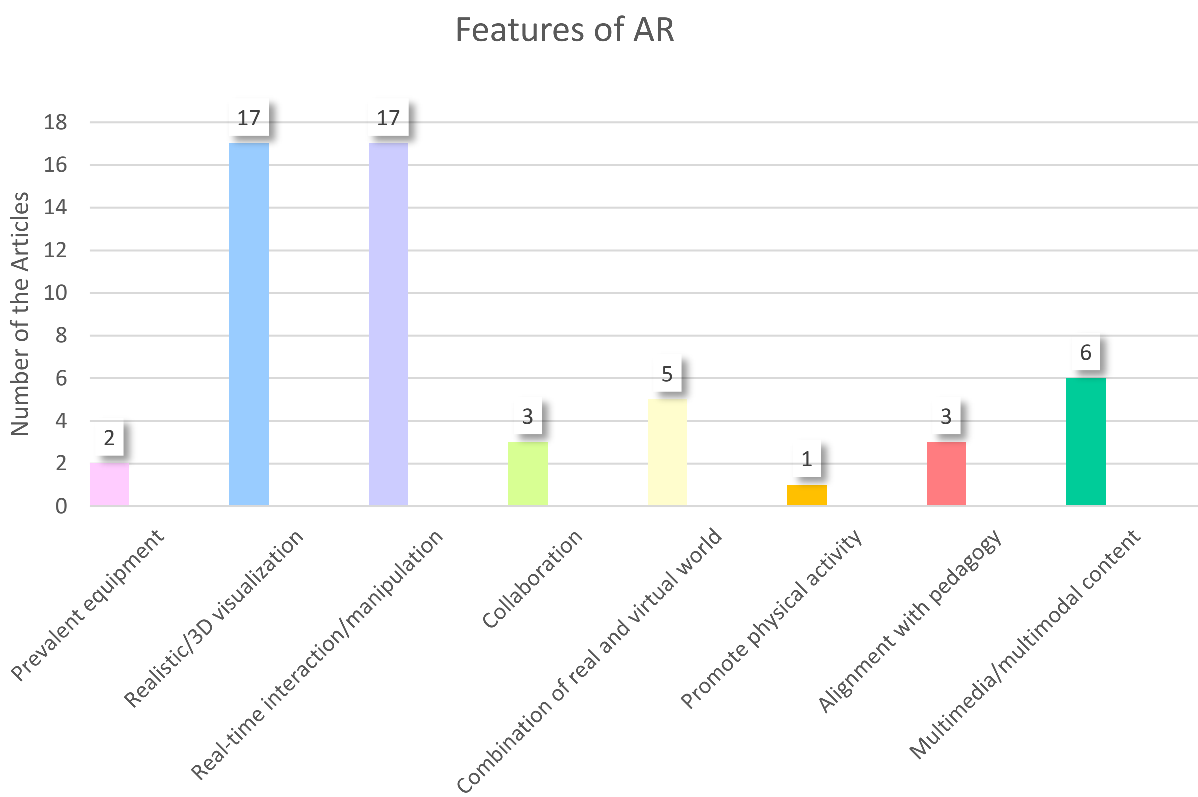


Figure 7. Features of AR mentioned in the selected studies.

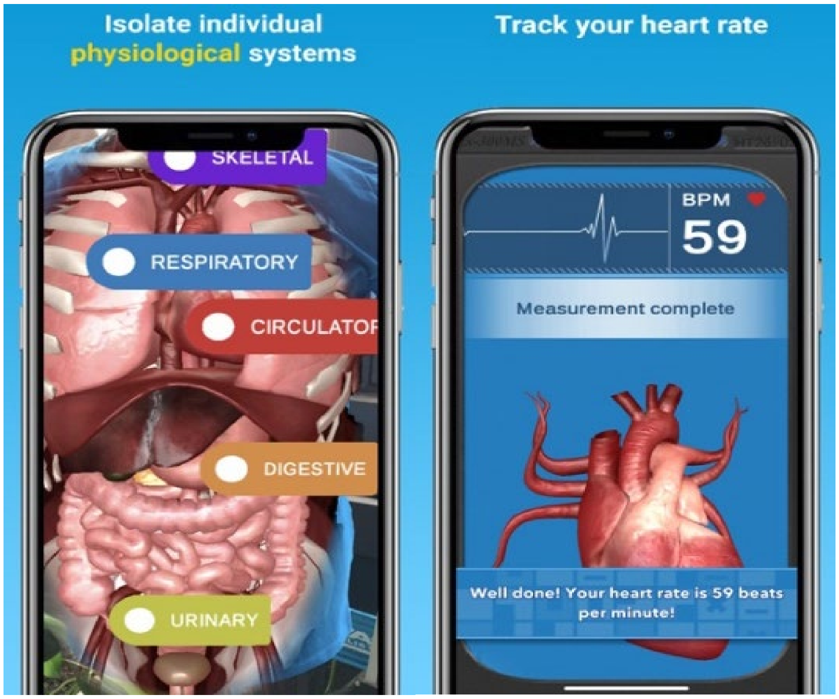


Figure 8. Screenshots of Virtuali-Tee (App Store, n.d.).[4]

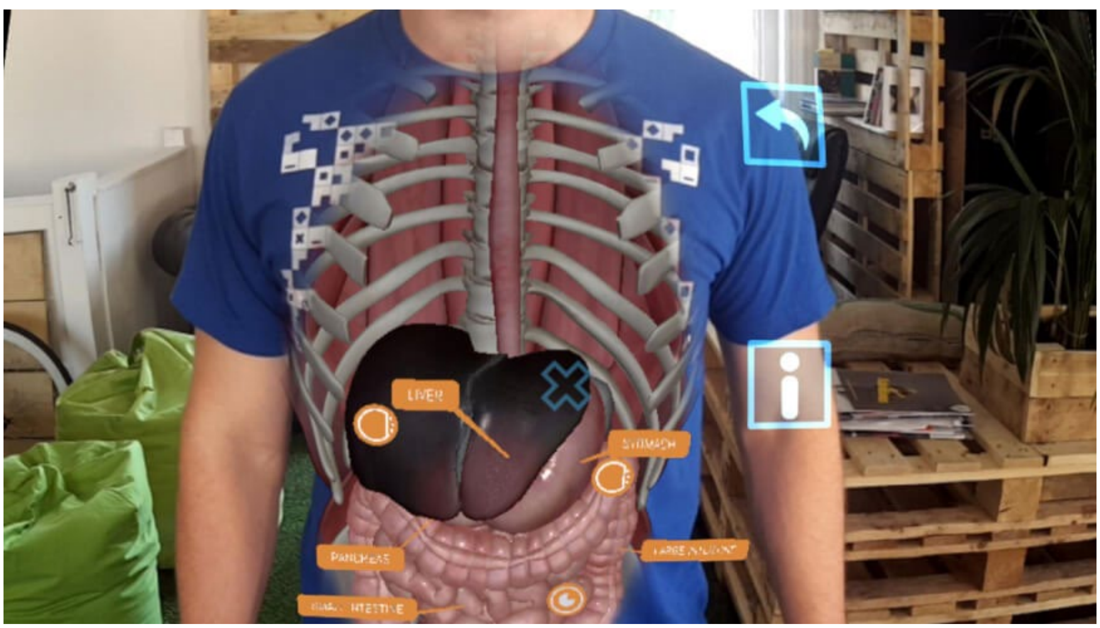


Figure 9. Virtual human organ objects in Virtuali-Tee (The Medical Futurist, 2018).[5]

[4] Virtuali tee application. [Image]. (n.d.).
[5] Virtual human organs with Virtuali tee application. [Image]. (2018).

Realistic/Three-Dimensional Visualization

AR allows learners to manipulate and learn content from a 3D perspective (Yoon, Anderson, Lin, & Elinich, 2017). Through AR-based instructional materials, learners obtain opportunities to examine new concepts from different perspectives, which does not commonly happen at school (Sirakaya & Çakmak, 2018b). Unlike 2D shapes, 3D shapes have not only length, width, and height but also depth, similar to how humans see the physical world. For instance, the anatomy of the human body and the structure of the earth cannot be easily visualized with 2D materials like images and animation (see Figure 10). AR technology offers sharp, realistic visual materials, which could catch learners' attention (Bhagat et al., 2019; Karagozlu et al., 2019; Sirakaya & Çakmak, 2018b), promote understanding (Bhagat et al., 2019; Cai, Liu, Yang, & Liang, 2019; Chen et al., 2020; Fidan & Tuncel, 2019), and prevent misconceptions (Sirakaya & Çakmak, 2018b). Therefore, learners are supported in their learning of information by AR technology.

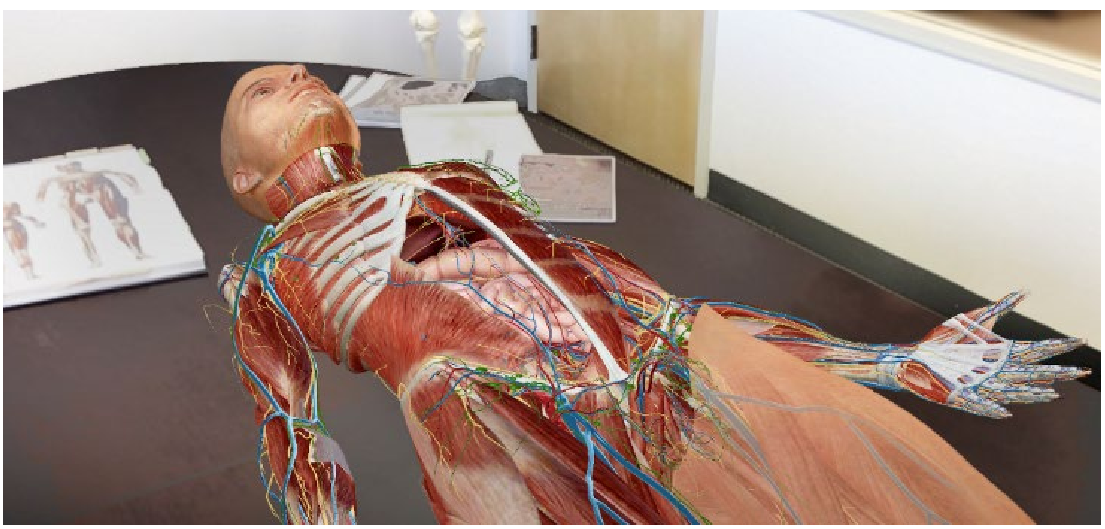


Figure 10. 3D visualization offered by AR technology (Jeahnig, 2018).

Multimedia/Multimodal Content

Of the 18 included studies, 6 stated that AR technology can help elaborate and deliver content by presenting multimedia and/or multimodal instructional materials. When students are just provided a textbook and/or handout, information is provided only in a 2D format, including text and some static images. As shown in Figures 11–14, AR technology offers the potential for digital learning materials, including images, animations, audio, and videos, both 2D and 3D and visual and acoustic, and displays them over real-world environments. Thus, such technology can render content much more comprehensible and supplement learners' sensory perceptions of the real world, which could promote their understanding of content (Ibáñez et al., 2020; Sahin & Yilmaz, 2020). Multimedia and/or multimodal instructional materials are mostly used in marker-based AR applications with paper-based handouts. Once a student scans a marker on the handout, interactive materials, such as videos, 3D objects, and animations, will appear on the mobile device's screen. In such cases, AR technology helps to quickly deliver multimodal content and facilitate effective learning (Nasongkhla, Chanjaradwichai, & Chiasiriphan, 2019; Sahin & Yilmaz, 2020).

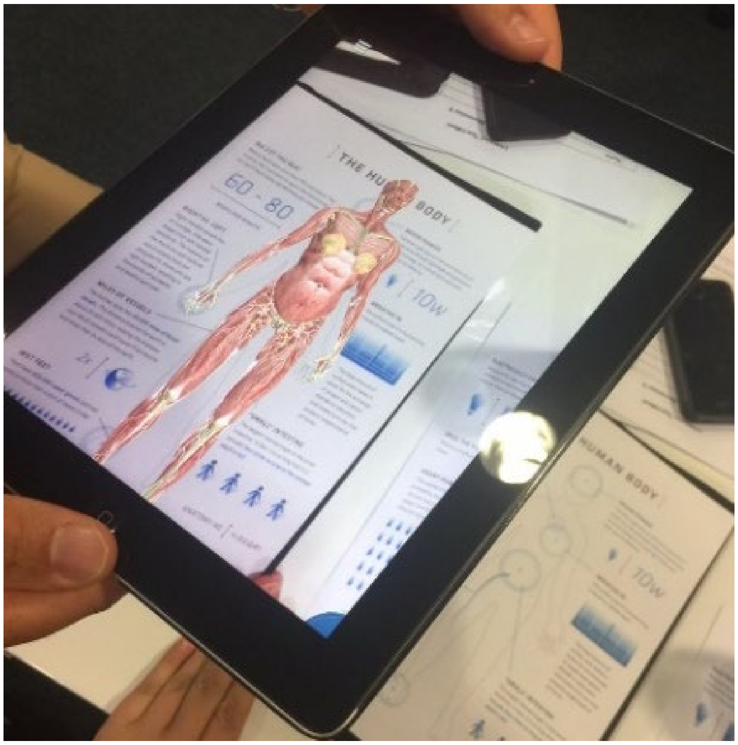


Figure 11. 3D AR image layered over a textbook page (YSAR, 2016).[6]

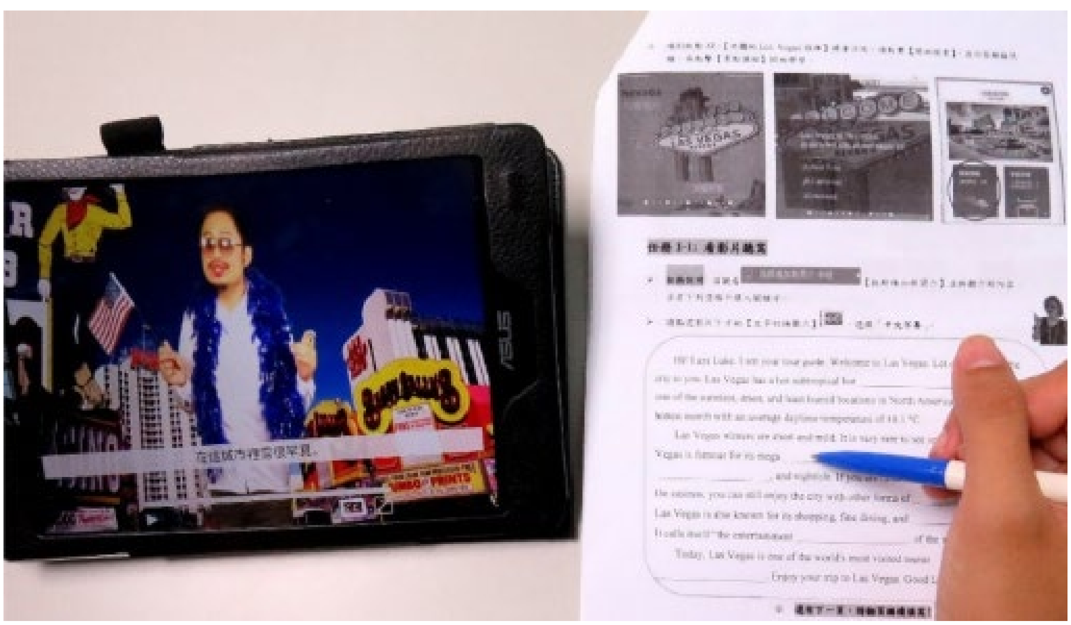


Figure 12. AR video triggered by a handout (Chen et al., 2020, p. 13).

[6] Augmented human body anatomy. [Image]. (2016).

Figure 13. 3D AR animation (Fidan & Tuncel, 2019, p. 6).

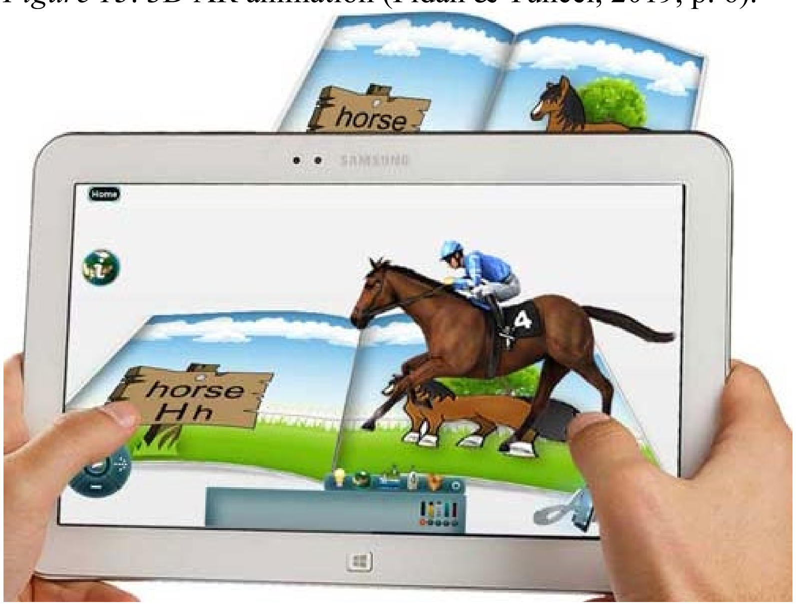


Figure 14. Multimedia/multimodal AR content linked to a book (Yantram Architectural Studio, 2016).[7]

[7] Multimodal AR content. [Image]. (2016).

Combination of the Real and Virtual Worlds

AR enables learners to perceive virtual elements as part of a physical environment by layering virtual objects over the real world (Yoon et al., 2017). The virtual object could be text, an image, an animation, or a video to help learners understand phenomena in more concrete ways. The combination of the real and virtual worlds is a distinct feature of AR that differentiates it from VR. Unlike VR, AR does not isolate learners from the physical world and retains their awareness of their own bodies. Additionally, AR is more likely to promote learner–content interactions since the learner can touch and dynamically manipulate digital objects (Bhagat et al., 2019). Figures 15 and 16 show an example AR application in which students are quizzed about butterfly anatomy. They select the topic that they want to review by touching its name. By tapping on and placing an arrow pointing to the butterfly's body parts, they can check their knowledge.

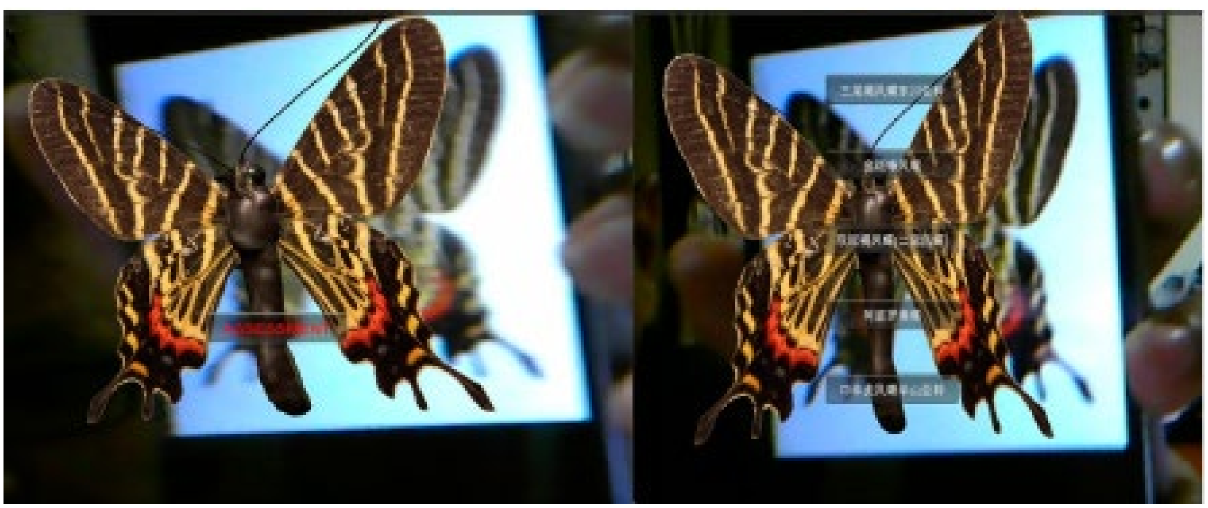


Figure 15. Quiz about butterfly anatomy embedded in an AR application and its topics (Bhagat et al., 2019, p. 6).

Figure 16. Examples of questions about butterfly anatomy (Bhagat et al., 2019, p. 6).

Collaboration

Three of the 18 studies emphasized that AR technology can support collaborative instructional activities (Bressler, Bodzin, & Tutwiler, 2019; Cheng, Wang, Cheng, & Chen, 2019; Yoon et al., 2017). Two employed AR-based games—MathMon and School Scene Investigators: The Case of the Stolen Score Sheets—that provide students with quests to accomplish a final goal (Cheng et al., 2019). For the learning activities involving these games, students were assigned to a group and worked collaboratively to complete the quests. The studies found that physical collaboration with AR-based learning materials positively impacted students' motivation (Bressler et al., 2019), and interaction allowed the learners to undergo iterative trial and error processes (Cheng et al., 2019). In the study by Yoon et al. (2017), which utilized AR technology in informal environments to teach physics concepts, the students were not officially grouped. However, they found that the students naturally gathered around the AR device and interacted with the teacher and other students, which could have improved their understanding of the physics concepts. Thus, AR technology could facilitate physical social interaction while learning and have the potential to enhance collaborative learning activities.

Alignment with Active Pedagogical Theories

Due to its nature that AR embodies a realistic context, AR aligns well with some pedagogical theories, especially constructivist learning theories such as problem-based learning (PBL; Fidan & Tuncel, 2019), inquiry-based learning (Abdusselam & Kilis, 2018), experiential learning (Chen et al., 2020; Xiao et al., 2018), and in situ learning (Tomara & Gouscos, 2019). Fidan and Tuncel (2019) indicated that the reason PBL works well with AR technology is that both relate to realistic contexts. AR technology involves dynamic and realistic learning environments, and PBL seeks a hands-on learning experience based on a realistic context. Specifically, PBL provides learners complex real-world problems and requires them to solve the problems to promote them to comprehend concepts and principles. AR enables the learners to visualize and understand problems in the real world, gather information about problems, analyze the underlying factors, and find solutions by supporting authentic learning environments with AR-specific features (i.e., 3D visualization, combination of the virtual and physical worlds, and real-time interaction). Other pedagogical theories also align with AR technology, as will be explained later in this report. As a result, it can be inferred that students' learning could be enhanced by incorporating AR learning environments with pedagogical and instructional approaches.

Dependency on Devices

At least one device must be employed in order to use AR technology. Although many devices for AR are not ubiquitous, relatively common and accessible devices, such as smartphones and tablets, are often utilized. This allows diverse people from different contexts to more easily access AR technology. If such equipment were plentiful at schools, teachers would be able to utilize a much wider range of instructional strategies that include AR in order to provide learners with diversified learning experiences. Tomara and Gouscos (2019) noted that an AR-based learning environment that includes mobile devices offers possibilities for in situ learning without special equipment. For example, in one case, AR allowed many students to experience microscopic organisms during a science class due to the higher penetration of mobile devices than microscopes in schools (Abdusselam & Kilis, 2018).

Increase of Physical Activity

Location-based AR encourages physical activity because students need to find and go to a specific location in order to prompt the appearance of a virtual object on their device and thus engage in AR-based learning activities (Ruiz-Ariza, Casuso, Suarez-Manzano, & Martínez-López, 2018). For example, in order to find Pokémon using Pokémon GO, an AR-based game, a person wanders around to discover locations that trigger Pokémon to appear on their mobile device. Marker-based AR can also encourage physical activity. Hsu, Wenting, and Hughes (2019) researched a final project called AR Campus Tour Guide, in which students could apply and integrate what they learned about AR with their teacher. The students produced a campus tour guide with AR technology in which users take photos to trigger virtual objects, interview others on campus, and assemble information. Visitors and students engaging in the AR campus tour must also engage in physical activity. Therefore, AR-based activities could enhance physical activity.

Advantages of Augmented Reality

Due to the unique features of AR mentioned above, research indicates that it is advantageous in education settings (see Figure 17).

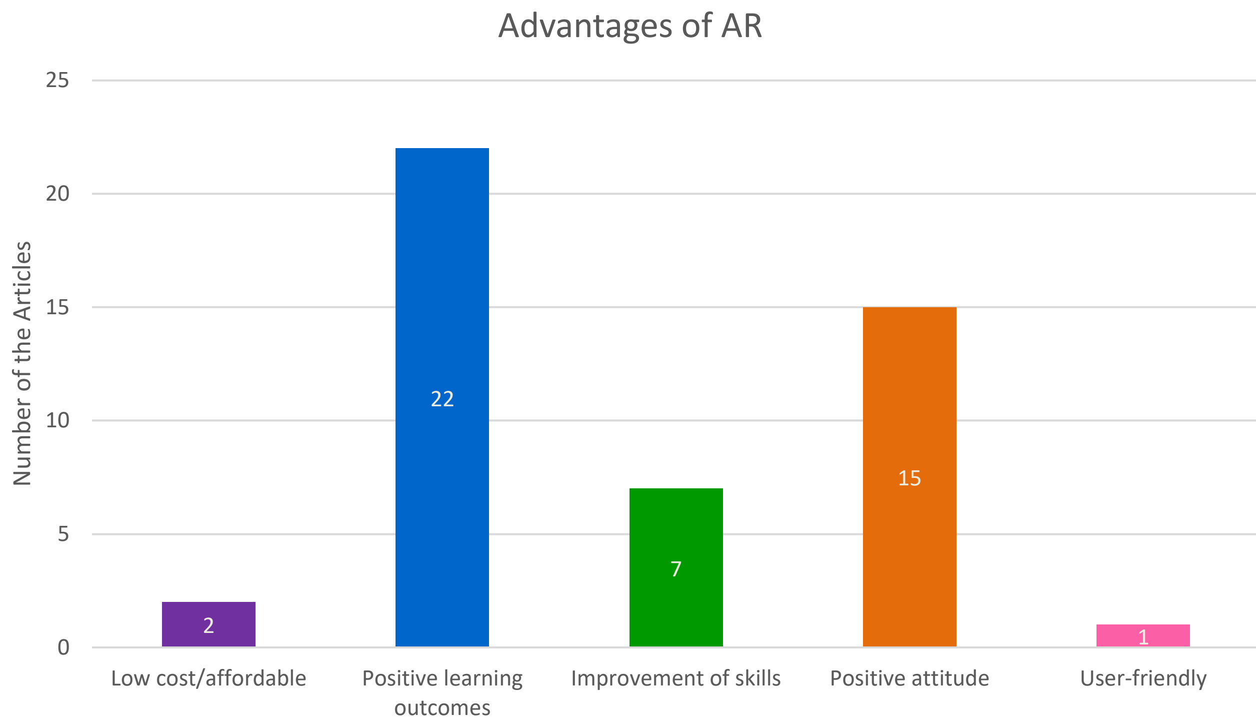


Figure 17. Frequency with which the advantages of AR are discussed in the reviewed studies.

Improvement of Academic Achievement

Many studies found that primary and high school students utilizing AR technology achieved higher academic performance than those who used web-based lessons or traditional methods (Bursali & Yilmaz, 2019; Georgiou & Kyza, 2018; Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014). AR had a positive influence on academic achievement in both science (Georgiou & Kyza, 2018; Ibáñez et al., 2014) and literacy (Bursali & Yilmaz, 2019). Bursali and Yilmaz (2019) revealed that AR affected not only students' immediate learning outcomes but also their retention over the three weeks of the study. They also implied that students' learning can be supported by combining AR with game- and problem-based learning. It is important to note that the same results were achieved regardless of the type of AR applied. Cai, Chiang, Sun, Lin, and Lee (2017) incorporated an School Scene Investigators: The Case of the Stolen Score

Sheets (SSI) AR (i.e., marker-based AR) game with problem-based learning by giving students a mission to find the criminal who stole test sheets. The study indicated that students' flow of and interest in learning were significantly enhanced. Likewise, Mystery at the Lake, which combined a location-based AR game with problem-based learning, increased students' immersion and motivation to learn (Georgiou & Kyza, 2018). The researchers indicated that the results were due to the affordances of AR in terms of visualization and immersion. Indeed, the students with higher AR immersion attained better learning outcomes and vice versa (Georgiou & Kyza, 2018). Likewise, high school students employing AR applications achieved higher posttest scores for visualization questions than those using web-based materials, even though the two groups who participated in Ibáñez et al.'s (2014) study were provided visual instructional materials.

Enhancement of Learning Retention

Bursali and Yilmaz (2019) revealed that AR affected not only students' immediate learning outcomes but also their retention over the three weeks of the study. The researchers found that the students who read with AR materials remembered more of the texts throughout the study compared to the students who read the texts without any technological support.

Concretization and Visualization of Concepts That are Difficult to Observe

As AR enables visualization of concepts, studies have shown that students learning subjects that involve abstract concepts, such as math (Cai et al., 2019), biology (Erbas & Demirer, 2019), physics (Yoon et al., 2017), and earth science (Sahin & Yilmaz, 2020), achieved higher scores than students who learned the subjects in a conventional way. Thus, it is likely that AR applications are an effective way to teach abstract concepts or objects that are too small or dangerous to observe.

Low Cost/Affordability

As mentioned above, mobile devices are often employed as a tool for AR realization. Scientific equipment, like microscopes, are not as common or affordable as mobile devices, such as smartphones and tablets. Thus, schools may reduce the cost of replacing expensive scientific equipment by using AR technology instead. Additionally, compared to VR, which mostly requires expensive and heavy devices like a head-mounted display to connect to a virtual environment, the equipment required for AR is much more affordable, since AR environments can usually be prepared with lighter and cheaper smart devices (Bressler et al., 2019). Therefore, it can be stated that AR is relatively affordable.

User-Friendliness

A study showed that students who employed AR applications were satisfied with the application, found it easy to use, and would like to use it in the future (Karagozlu et al., 2019). Specifically, the results showed that there were significant positive differences before and after a learner used the AR application in terms of usage satisfaction (e.g., "I enjoy the lessons conducted with AR applications"), usage anxiety (e.g., "AR applications make learning more difficult for me as they confuse me," "It is difficult to use AR applications"), and usage willingness (e.g., "I would like it to be used in other classes as well"). Additionally, Bressler et al. (2019) reported that, unlike VR, AR does not cause nausea and discomfort by using virtual reality technology. From these results, it seems clear that AR is a relatively user-friendly technology.

Active In-Class Participation

Since AR activities are intriguing, students are motivated and more willing to participate in class activities (Bursali & Yilmaz, 2019; Erbas & Demirer, 2019; Karagozlu et al., 2019;

Sahin & Yilmaz, 2020). Yoon et al. (2017) reported that one of the affordances of AR is to support learning by facilitating engagement in inquiry and encouraging learners to explore, ask questions, collaborate with others, and find results or solutions. Therefore, there is much potential for AR to foster students' active engagement in class activities.

Limitations of Augmented Reality

There are some limitations of AR. Six categories of limitations are listed in Table 1.

Table 1

Limitations of AR Applications

Categories	Details	Source
Difficulties of use (*n* = 4)	• It was very difficult for less proficient learners to make full use of the AR-based application, which means that the application was not user-friendly for novice users. • Due to the complicated interface design, learners found it difficult to navigate the AR-based application. • There were some interface issues pertaining to the AR applications' compatibility with other mobile devices. • Low technical usability could lead to low learning satisfaction.	• Chen et al. (2020) • Ibanez, Portillo, Cabada, and Barron, (2020) • Tomara and Gouscos (2019) • Xiao et al. (2018)
Required equipment (*n* = 2)	• 'Limited penetration of mobile devices in public schools for learning purposes, in combination with the fact that AR technology has not been widely known until recently' (Tomara & Gouscos, 2019, p. 2). • Extra equipment and materials were needed for AR learning activities, such as mobile phones, tablets, spectra vision, and Leap Motion, which are not pervasive in these days.	• Tomara and Gouscos (2019) • Xiao et al. (2018)
Technical issues (*n* = 2)	• The application is running too slowly. • Low presentation quality. • Low sensitivity for recognition of markers. • GPS and Wi-Fi connection errors.	• Chen (2019) • Fidan and Tuncel (2019)

Cognitive overload (n = 2)	• Usability problems and usage of a complicated AR application could cause a learner to experience cognitive overload. • In the AR application, requiring multiple and mixed tasks led to excessive cognitive overload, which might negatively influence learners' learning outcomes.	• Chen et al. (2020) • Fidan and Tuncel (2019)
Limited functions (n = 1)	• In one case, a limited number/variety of microscopic organisms could be observed through an AR-based application used in a biology course. Thus, learners could not examine as wide a range of organisms as a real microscope allows.	• Abdusselam and Kilis (2018)
Physical impairment (n = 1)	• AR applications might cause bad eyesight and neck stiffness. • Arms and hands may feel pain due to holding a mobile device.	• Fidan and Tuncel (2019)

In terms of the usability of AR, one study reported that learners experienced interface issues regarding the application's compatibility with other devices (Tomara & Gouscos, 2019). Chen et al. (2020) also mentioned that some students found it difficult to navigate the AR application, which led it to be somewhat disruptive during the learning activity. AR is susceptible to its interface design. Thus, when teachers create or select learning materials with AR technology by themselves, they should be knowledgeable about interface design in order to provide suitable materials for their students and content.

Tomara and Gouscos (2019) examined the process of developing a physics-related AR learning environment. The results showed that, due to the use of limitedly distributed equipment for the AR learning activity, it would be difficult to implement AR-based classes in other middle and/or junior high schools. Technical issues were also reported in the studies. Specifically, AR applications occasionally caused GPS and/or Wi-Fi errors, low sensitivity in the recognition of markers (Fidan & Tuncel, 2019), and low resolution and presentation quality (Chen, 2019). These issues could definitely distract students' learning and negatively influence their attitudes toward AR and/or a subject. Two studies indicated that students who were not familiar with employing AR applications would experience cognitive overload when using them, hindering their learning (Chen et al., 2020; Fidan & Tuncel, 2019). The limited features of AR applications were also described as a limitation. For instance, an AR application for teaching biology, called MicrosAR, did not allow students to observe numerous kinds of organisms through the app (Abdusselam & Kilis, 2018). Lastly, students were concerned that playing with an AR application might damage their physical condition, including their eyesight (Sirakaya & Çakmak, 2018b). Teachers should be aware of these limitations and examine whether issues exist in the application they plan to use in order to avoid situations that hamper students' learning.

Integration of Augmented Reality in Classrooms

This section explains how teachers have used AR technology based on the 18 reviewed articles. It describes which types of AR have been commonly utilized, in which subject areas AR has been frequently integrated, which kinds of supplemental materials are utilized with AR, which devices are commonly deployed for AR, which pedagogical theories or frameworks work well with AR technology, and which platforms are widely used for AR technology.

Types of Augmented Reality Used by Teachers

The following section explains which types of AR have been commonly implemented in education as well as how each type of AR is employed in classroom settings. As shown in Figure 18, 17 articles focused on marker-based AR. All of the applications examined in the articles utilized QR codes as markers, and students scanned the code through devices such as iPads and smartphones. Then, virtual objects, such as butterflies, microscopic organisms, and celestial bodies, appeared on the screen.

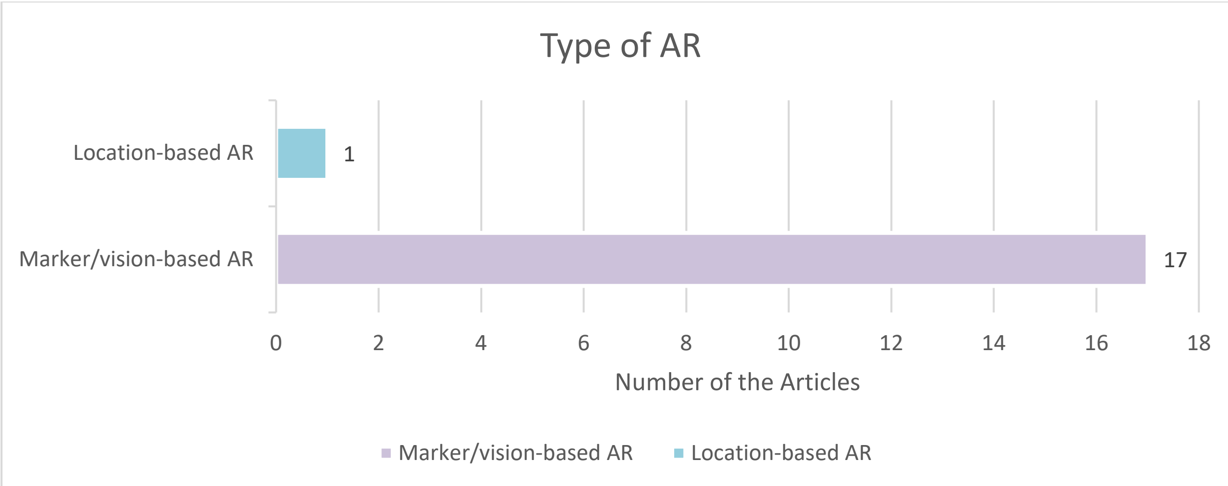


Figure 18. Frequency of types of AR reported in the reviewed studies.

One of the 18 studies focused on location-based AR (Ruiz-Ariza et al., 2018). The students needed to go to specific GPS coordinates to trigger the appearance of virtual objects on their screen. AR-based motion sensing is another type of AR that does not use an image as a marker or code to produce simulated objects. Instead, gestures prompt the appearance of these objects. For instance, in a study by Yoon et al. (2017), a person stood in front of a Bernoulli blower device and brought a hand close to a floating ball. The device sensed the bodily gesture and reacted to it by showing different digital augmentations on the screen in real time.

Overall, the marker-based AR has been more actively implemented than location-based AR or AR-based motion sensing. This might imply that marker-based AR has more advantages for application in middle school settings. One possible advantage is that it is very easy for teachers to manage their class and students since they do not need to go outside of the school. In contrast, location-based AR applications require students to leave the classroom, which makes it more difficult for a teacher to manage the class. Additionally, it might be much more convenient for teachers to design an intervention with marker-based AR. For location-based AR, the teacher needs to find an appropriate location to trigger each virtual object. Additionally, since the class is offered outside, very few instructional materials and/or tools may be available to employ during the class. This means that teachers should thoroughly plan their lessons in order to successfully complete them with location-based AR technology. On the other hand, for marker-based AR, teachers just need to create a marker that prompts the appearance of superimposed virtual objects (although they still need to make an effort to design the lessons). In other kinds of marker-less AR, like AR-based motion sensing, extra equipment, like a Bernoulli blower device (see Figure 19), which is not common or affordable for public educational institutions, is usually required. For these reasons, researchers might see more possibilities for marker-based AR, leading to a greater number of studies targeted at middle school or junior high school education.

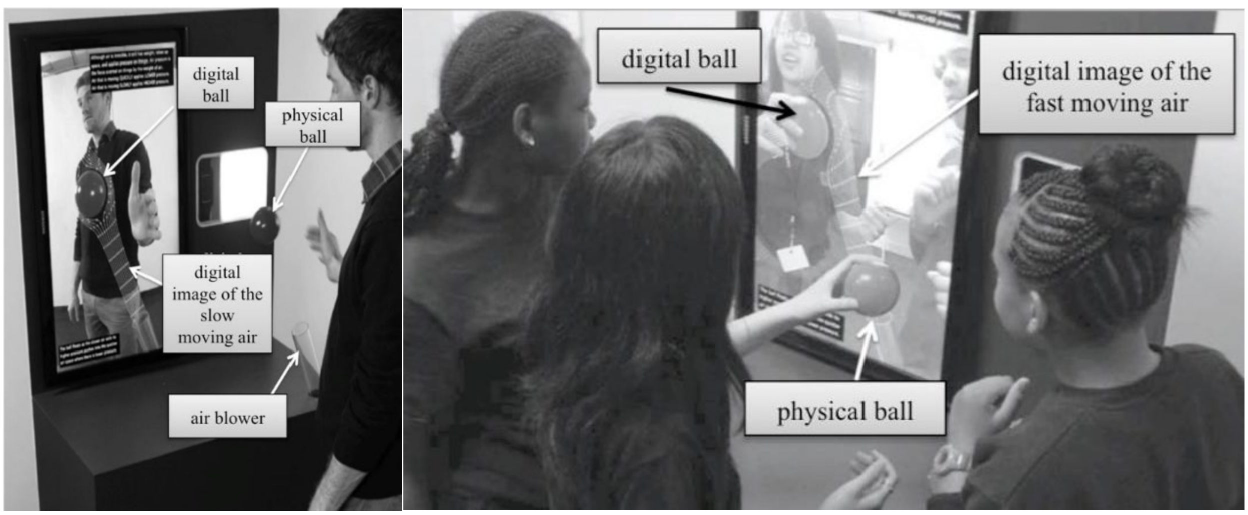


Figure 19. Students with Bernoulli's blowing device and the AR application (Yoon et al., 2017, p. 4).

Subject Domain

This section describes how AR technology has been implemented across subject areas based on information from the reviewed articles.

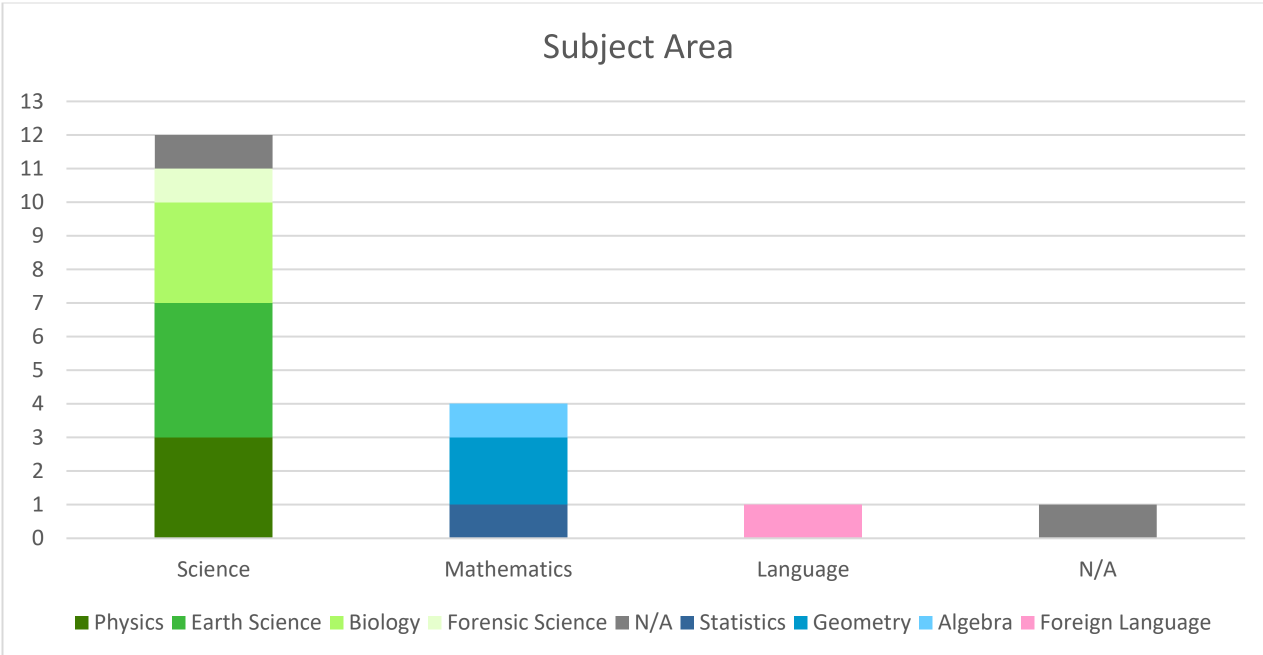


Figure 20. Frequency of subject domains in which AR has been applied in the reviewed articles.

As Figure 20 shows, 12 of the 18 studies focused on the subject of science, specifically biology (see Figure 21; Abdusselam & Kilis, 2018; Bhagat et al., 2019; Nasongkhla et al., 2019), forensic science (Bressler et al., 2019), earth science (see Figure 22; Ruiz-Ariza et al., 2018; Sahin & Yilmaz, 2020; Sirakaya & Çakmak, 2018b; Xiao et al., 2018), and physics (see Figure 23; Fidan & Tuncel, 2019; Tomara & Gouscos, 2019; Yoon et al., 2017). One of the studies did not mention which specific area within the science subject was chosen.

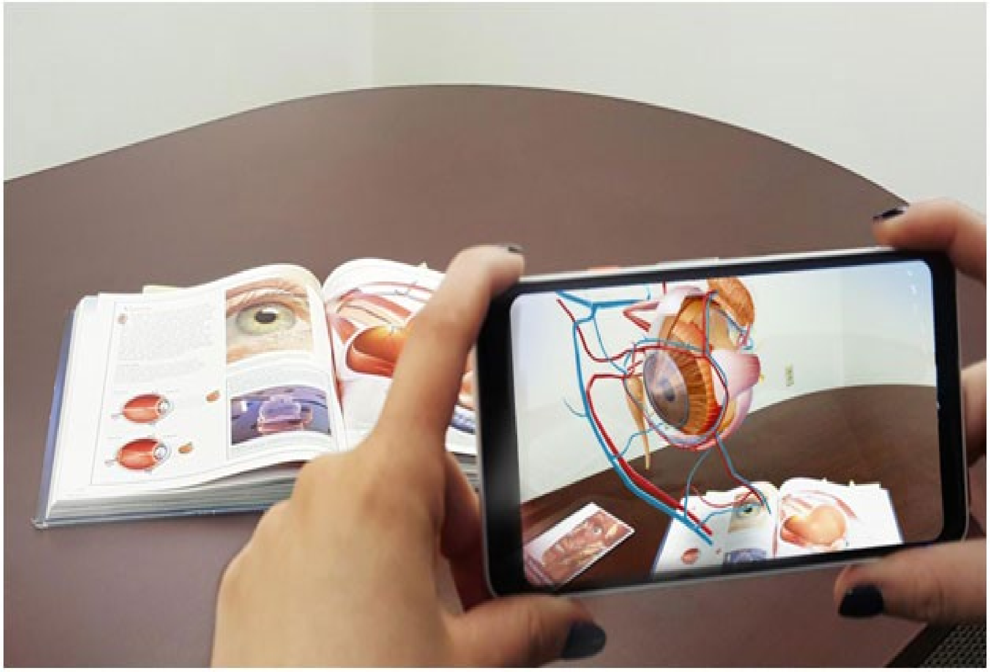


Figure 21. AR application used to teach biology (Lehrer, 2019).[8]

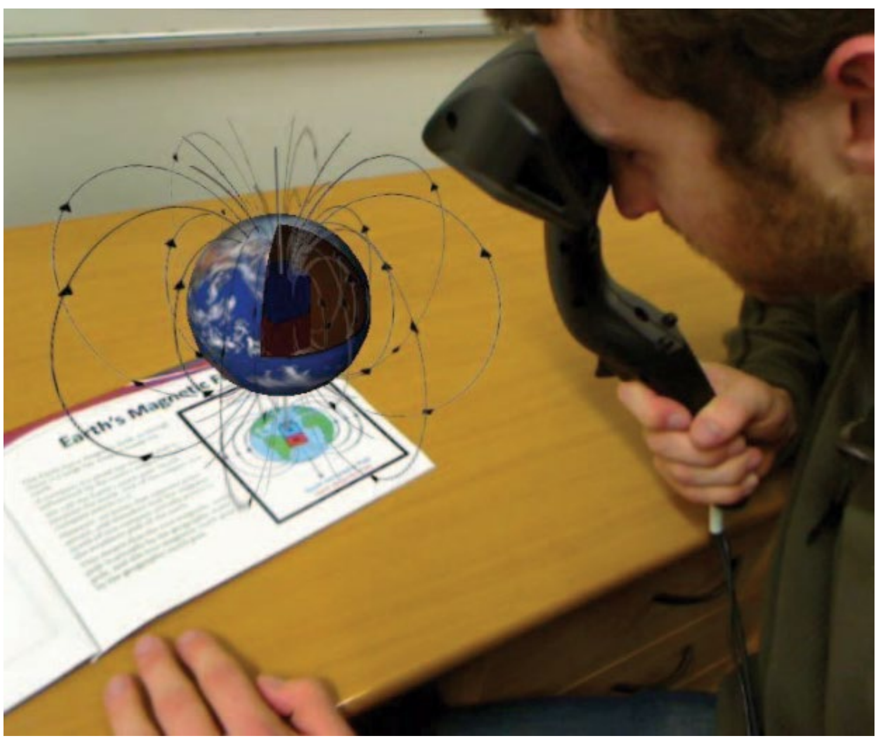


Figure 22. AR application used to teach earth science (Dünser, Walker, Horner, & Bentall, 2012).

[8] Virtual human eye anatomy in augmented reality. [Image]. (2019).

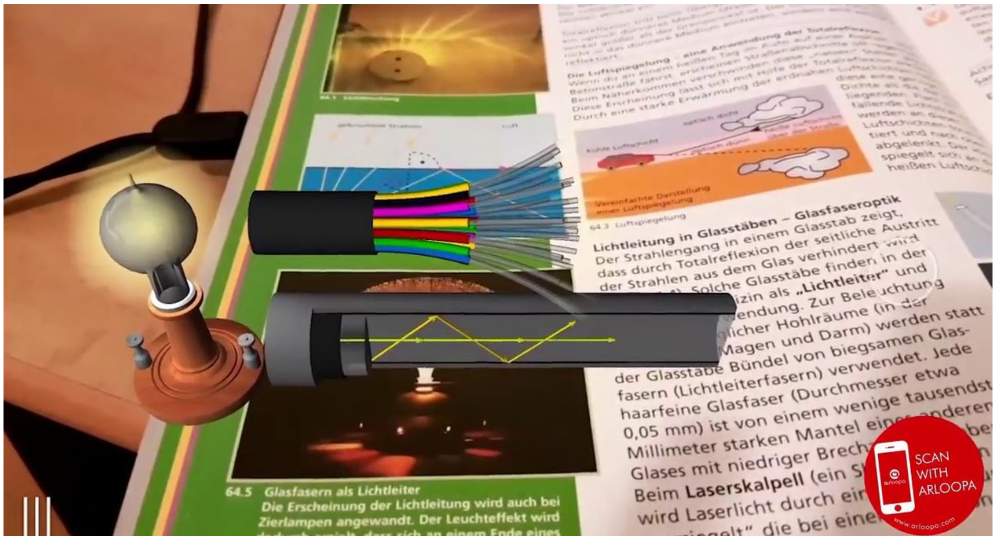


Figure 23. AR application used to teach physics (AI Spartans, 2017).[9]

The second most frequently examined subject domain is mathematics (n = 4). Specifically, researchers focused on algebra (Chen, 2019), geometry (see Figure 24; Chen, 2019; Ibáñez et al., 2020), and statistics (Cai et al., 2019). One of the four studies did not state a specific mathematics topic.

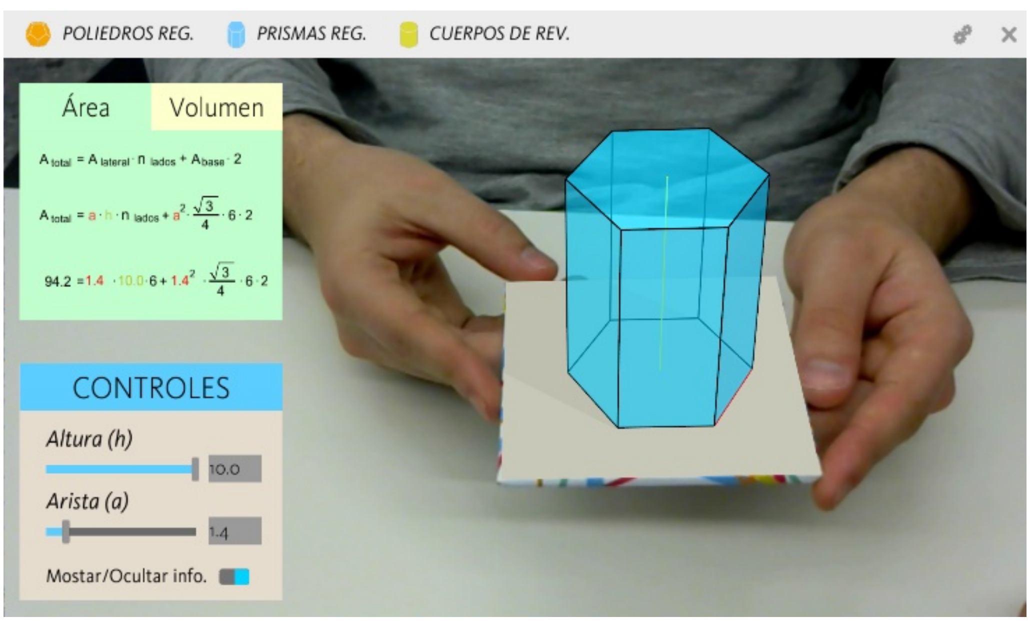


Figure 24. AR application used to teach math (Arloon, n.d.).

[9] Augmented reality physics book. [Image]. (2017).

Only one study focused on foreign language (Chen et al., 2020), and the other study examined the cognitive and affective domains (Ruiz-Ariza et al., 2018). For language learning, students were immersed in a foreign language context through an AR-based platform. When Chinese students scanned a mark with a name of the U.S. city, a situation happening in the city was provided through an AR application called Traveling around the United States of America so that they were able to practice English under the real context. This allowed them to practice the language in a realistic context, which is more likely to promote effective learning of a foreign language. However, most research focused on science and mathematics due to the features of AR (i.e., visualization, combination of physical and virtual environments, and real-time interaction), which enables students to observe and concretize things that are difficult to observe in daily life, such as probability, the solar system, and genes.

Theoretical Approaches

This section identifies which theoretical framework aligns well with AR and enables its successful integration in education. The theoretical frameworks were divided into three main categories: pedagogical/learning theories, instructional system design frameworks, and design theories (see Table 2).

Table 2

Theoretical Approaches Aligned with AR

Category	Instructional Approach/ Model	Details	Reference
Constructivist Learning Approaches	Collaborative Learning (n = 2)	• Students were grouped and collaboratively completed missions by solving math questions provided in an AR-based game application. • Students collaboratively work to find a person who stole test answers from the principal's office.	• Bressler et al. (2019) • Cheng et al. (2019)

	Inquiry-based Learning (n = 2)	• Students conducted experiments by making a hypothesis, observing organisms, testing the hypothesis, and discovering new knowledge via an AR-based application. • Students played with Bernoulli's blower device and were able to make observations, investigate, and interpret data regarding Bernoulli's principles shown in the AR system.	• Abdusselam and Kilis (2018) • Yoon et al. (2017)
	Experiential Learning (n = 2)	• Students experienced situations in foreign countries through an AR application in order to learn a foreign language. • Students went through a learning scenario regarding earth science and manipulated eight planets using AR technology.	• Chen et al. (2020) • Xiao et al. (2018)
	Problem-based Learning (n = 3)	• Students were given 10 mathematics questions through an AR application called MathMon. • Students were provided problem scenarios related to physics concepts, such as friction force and water resistance, for 11 weeks through an AR application called FenAR. • A context-dependent set of items consisting of a series of genetics questions that required students to generate, analyze, compare, and contrast was displayed in an AR system.	• Cheng et al. (2019) • Fidan and Tuncel (2019) • Nasongkhla et al. (2019)
	Game-based Learning (*n* = 3)	• Students learned by playing the games such as School Scene Investigators: The Case of the Stolen Score Sheets, Pokémon GO and MathMon.	• Bressler et al. (2019) • Cheng et al. (2019) • Ruiz-Ariza et al. (2018)
	Informal Learning (*n* = 1)	• Students learned Bernoulli's principles at a museum without the formal format of a classroom.	• Yoon et al. (2017)
	Theme/Narra-tive-based Learning (*n* = 2)	• By following the story of the AR application Traveling around the United States of America, students learned English in context. • Students played the AR-based game School Scene Investigators: The Case of the Stolen Score Sheets to complete its storyline. They needed to investigate who stole test answers from the	• Bressler et al. (2019) • Chen et al. (2020)

		principal's office by interviewing four suspects, collecting data, and analyzing evidence.	
Instructional System Design Theories	[10]ARCS Model (n = 2)	• This model was applied to develop an AR-based application. • Attention: Opening questions and multimedia content were used to draw students' attention. • Relatedness: Examples were provided to connect new information to prior knowledge. • Confidence: Questions were reviewed and immediate feedback was offered. • Satisfaction: A new scenario was given for further application and comprehensive assessment of knowledge.	• Chen (2019) • Ibáñez et al. (2020)
	5E Learning Model (n = 1)	• Engage: Open questions are provided and concepts regarding microscopic organisms are introduced to make students engage in class. • Exploration: Students explore the concepts and gain important information related to the topic by participating in learning activities. • Explanation: The topic is explained to students and they are given opportunities to explain the topic to others. • Elaborate: Students are asked questions to elaborate on what they learned. Evaluation: Students' learning outcomes and/or products are evaluated.	• Abdusselam and Kilis (2018)
Design Theory	Design Princi-ples/Require-ments (n = 1)	• Students are allowed to alter parameters at their own pace. • They are allowed to repeat previous steps in the activities if necessary. • Worksheets are designed with instructions to help students manipulate the superimposed objects and encourage them to reflect upon the implications of their actions. • Collaborative elements are included. • The use of textual directions in the AR interface is minimized.	• Tomara and Gouscos (2019)

[10] An instructional design model that focuses on the motivational aspects of learning environment. The model consists of four components attention, relatedness, confidence, and satisfaction, which is abbreviated as ARCS.

AR-based instructional activities were supported by pedagogical approaches, instructional system design frameworks, and user interface design theory in order to enhance the quality of instruction involving AR technology and students' learning outcomes. As shown in Table 2, many studies aligned AR-based learning activities with constructivist learning approaches. According to constructivist learning theory, a learner builds systems of meaning and constructs knowledge through their own experiences (Richardson, 2003). The learner is considered to be active, not passively accepting knowledge from others but actively building knowledge by engaging in active learning experiences. Additionally, they construct understandings by interacting with the world (e.g., observing and examining phenomena and applying knowledge in real settings) and others, such as teachers and peers (e.g., conversations and discussions). Thus, constructivists argued that learning should not be isolated from real contexts. Due to the features of AR, the constructivist learning approach is well aligned with AR. Specifically, AR enables students to actively interact with learning content in real time and immerses them in learning by providing realistic visualizations and multimodal content, in line with constructivists' arguments.

Instructional approaches stemming from constructivist learning theory, including collaborative, game-based, experiential, inquiry-based, theme/narrative-based, informal, and problem-based learning, were well incorporated with AR-based learning activities. In experiential, inquiry-based, and PBL, students are situated in a contextual learning environment and/or tasked with solving real-life problems. The results of the studies integrating such instructional approaches showed that AR-based classes had a positive impact on learning satisfaction (Fidan & Tuncel, 2019), academic performance regarding language (Chen et al., 2020), biology knowledge (Abdusselam & Kilis, 2018), physics knowledge (Fidan & Tuncel, 2019), and analytical ability (Nasongkhla et al., 2019). It could be stated that student-centered activities with integrated AR technology are more likely to lead to positive learning outcomes for learners. This is supported by the study performed by Fidan and Tuncel (2019), which compared learners' academic achievement between a PBL in an AR group, a PBL-only group, and a traditional lecture group. In this study, a problem scenario that contained a real-life example of physics was offered to students (see Figures 25 and 26). To solve the problem, the students defined what they knew and did not know and identified information that they did not understand well. With information and logical reasoning, they generated and submitted the best solution for the problem. They could practice solving similar problems by answering the given complex real-world problems. The authors reported that the PBL with AR group had significantly higher learning achievement scores compared to the other two group, indicating that PBL and AR-based learning activities have substantial synergy (Fidan & Tuncel, 2019).

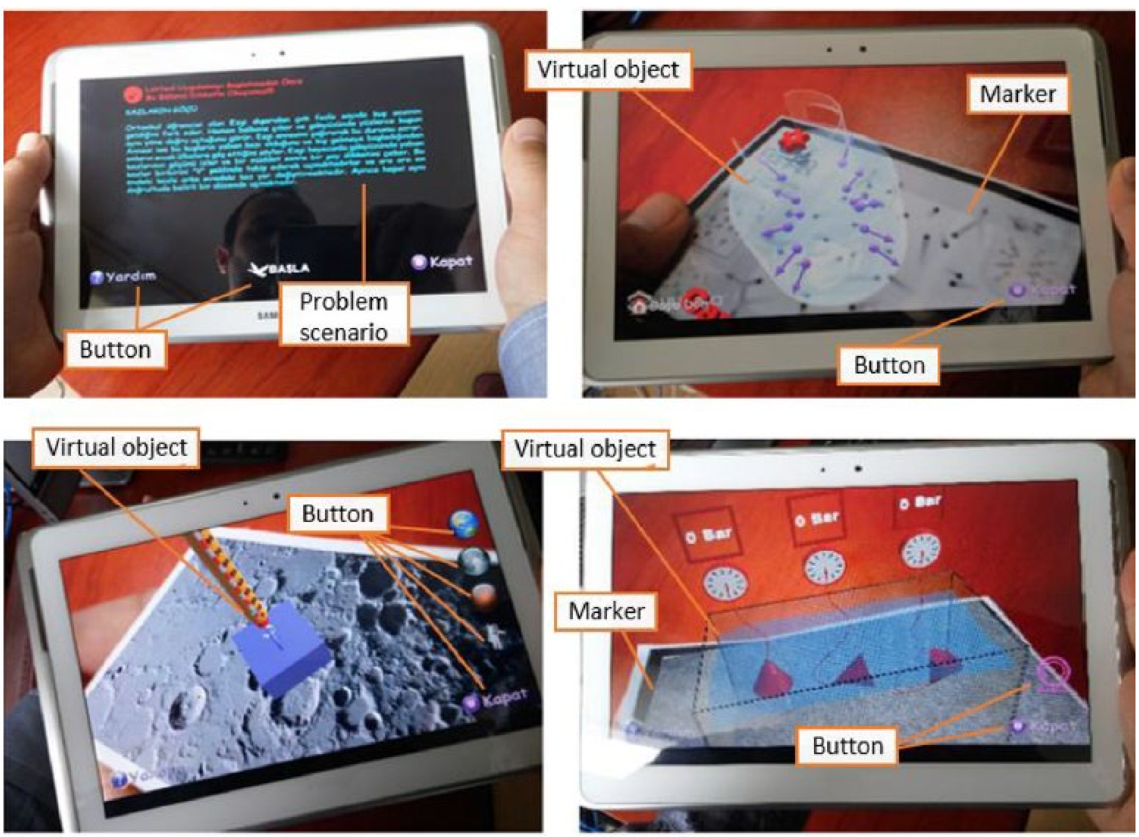


Figure 25. Examples of AR aligned with a PBL approach (Fidan & Tuncel, 2019, p. 7).

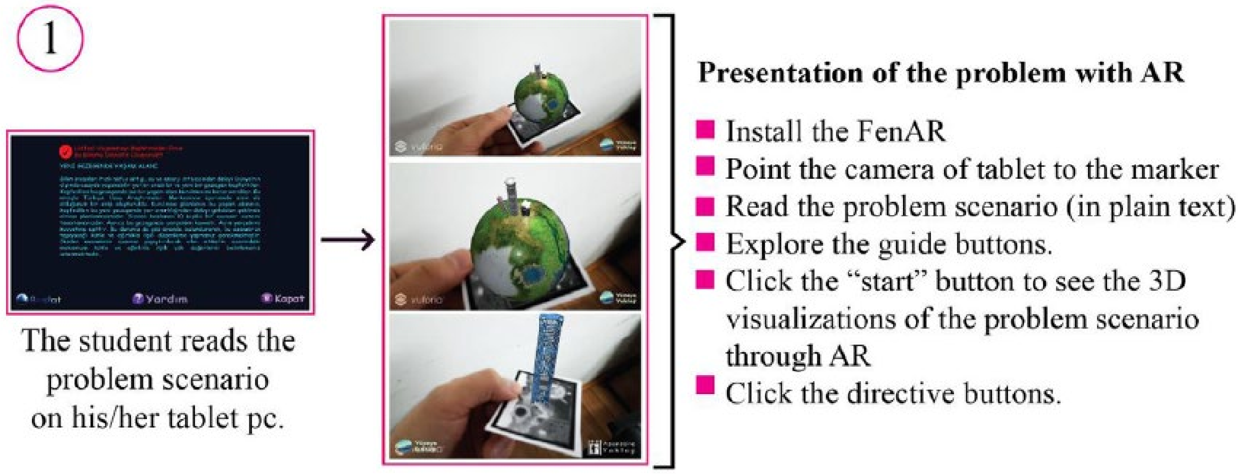


Figure 26. Example of a problem presented with AR (Fidan & Tuncel, 2019, p. 8)

AR-based learning activities also align well with game-based learning, which allows to students to practice skills and experience real-life scenarios in a non-threatening learning environment. One study by Cai et al. (2017) utilized an AR-based game called School Scene Investigators: The Case of the Stolen Score Sheets for a forensic science class. In this AR game (see Figures 27 and 28), the goal was to find a criminal who stole test questions from the principal's office. Students wandered around their school to find clues, which provided them with a better understanding of physics, to catch the criminal. The study found that the mobile AR game could facilitate immersion among both genders and all achievement levels, even though the AR game was not a voluntary but a mandatory classroom activity. In addition, learners who played Pokémon GO exhibited better cognitive performance, including improved memory, linguistic reasoning, and mathematical calculation ability. It also helped promote emotionality and a social culture by having students visit famous buildings, monuments and cultural places in the company of friends (Ruiz-Ariza et al., 2018).

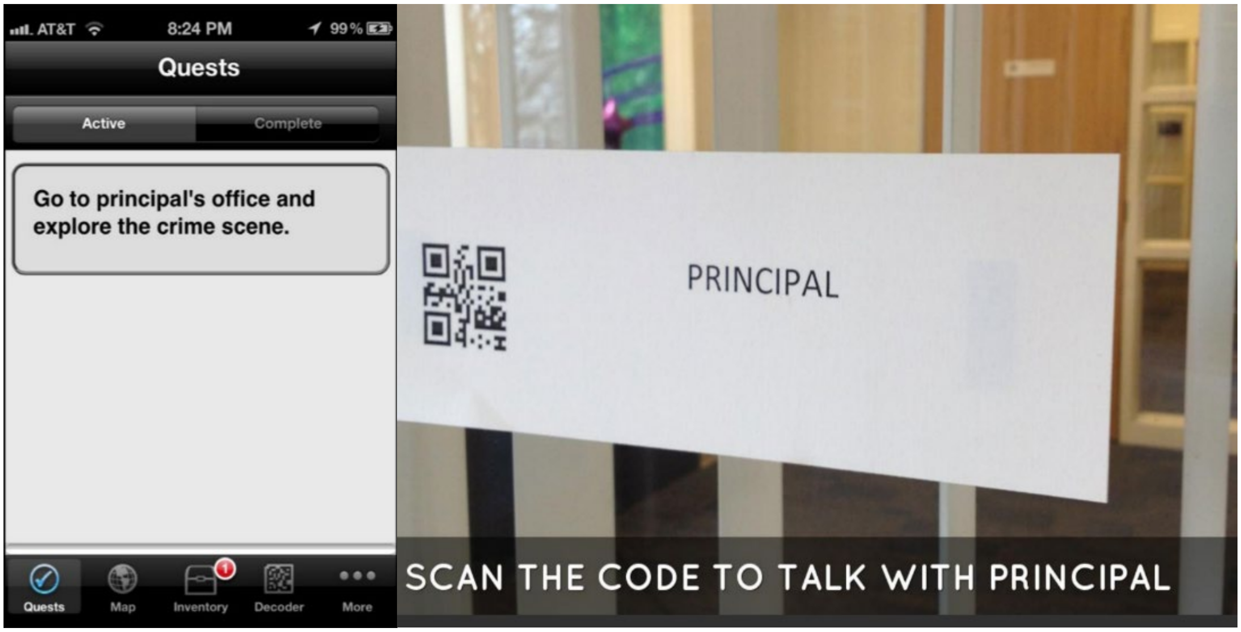


Figure 27. Screenshots from School Scene Investigators: The Case of the Stolen Score Sheets (Holden, 2015, p. 91).

Figure 28. Students playing School Scene Investigators: The Case of the Stolen Score Sheets (Holden, 2015, p. 94).

AR also supports collaborative learning. AR-based games, such as School Scene Investigators: The Case of the Stolen Score Sheets, Pokémon GO, and MathMon, include features that promote collaboration with multiple people and, as a result, social interaction while learning. This could improve students' engagement, especially for girls (Bressler et al., 2019). Thus, teachers should adopt AR-based games in order to promote middle school students' affective, cognitive, and/or attitudinal characteristics

AR-based learning activities can also incorporate narrative/theme-based learning, which is an instructional approach that designs learning circumstances with real-world stories or issues. Applying AR technology to narrative/theme-based learning is likely to enhance learners' motivation and engagement. The AR-based game called School Scene Investigators: The Case of the Stolen Score Sheets has a narrative in which learners investigate who stole test answers from the principal's office. Another AR-based application, Traveling around the United States of America, focuses on learning English by traveling around the United States. Chen et al. (2020) found that AR theme-based, contextualized learning of English as a second language could be applied to promote learners' motivation and attitudes in the beginning stage of learning. Bressler et al. (2019) also reported that School Scene Investigators is likely to yield a flow[11] experience for students. Students, especially girls, were much more likely to be interested and engaged in the AR-based learning activities when the activities involved either narrative- or theme-based learning. Thus, combining AR technology and narrative/theme-based learning has a significant positive impact on motivation and engagement.

The ARCS model by Keller (Chen, 2019) and 5E learning model (Abdusselam & Kilis, 2018), which is an instructional design model that contains five steps (engage, explore, explain, elaborate, and evaluate), were successfully employed to implement AR technology in a classroom. Instructional activities involving mobile AR applications based on the ARCS model were able to improve not only high-anxiety students' capacity in math but also their confidence

[11] The mental state in which a person performing an activity is fully immersed in a feeling of full involvement and enjoyment in the process of the activity.

and satisfaction in learning mathematics (Chen, 2019). Another study by Abdusselam and Kilis (2018) indicated that a technology-rich 3D AR learning environment stimulated learners' interest and motivation to answer questions in the engagement stage. Consequently, the 5E learning model and ARCS model are recommended when designing instruction that will be given in an AR technology environment.

Supplemental Materials/Devices

Of the 18 studies on instruction with AR, 7 utilized paper-based handouts as an instructional materials, including worksheets (Abdusselam & Kilis, 2018; Chen et al., 2020; Fidan & Tuncel, 2019; Nasongkhla et al., 2019; Tomara & Gouscos, 2019), activity booklets (Sahin & Yilmaz, 2020), and paper symbol cards (Xiao et al., 2018; see Figure 29).

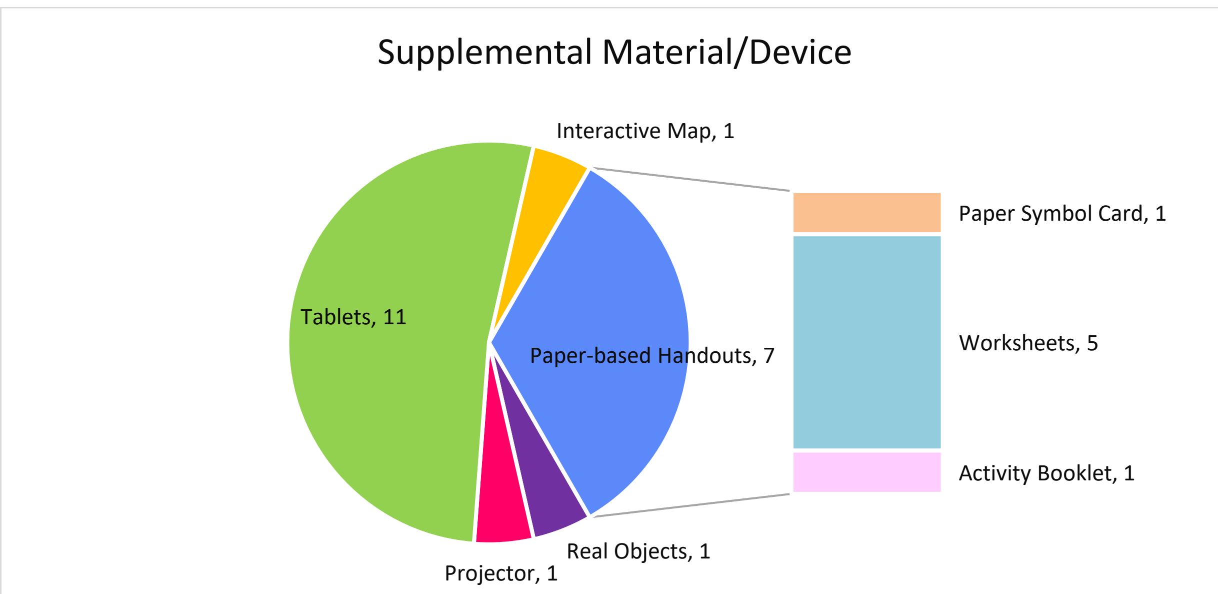


Figure 29. Frequency of supplemental materials/devices utilized with AR in the reviewed studies.

These paper-based handouts have two functions. First, images or markers like QR code can be embedded in the handouts to trigger virtual objects, such as 3D animation and quizzes, on the device that the learner is using during the class in order to promote learning (Abdusselam & Kilis, 2018; Bressler et al., 2019; Sirakaya & Çakmak, 2018a, 2018b). The other function is providing guidance and delivering knowledge to learners via either the handouts or an AR-based platform, such as a game (see Figures 30 and 31). One study by Abdusselam and Kilis (2018) used a worksheet as a learning material. Other supplemental materials include real objects such as cupcakes (see Figure 32), a projector, and an interactive map. In Sahin and Yilmaz's (2020) study, a projector was utilized in order to make students be on the same page in a classroom by projecting superimposed virtual objects from the AR-based activity booklet onto a board.

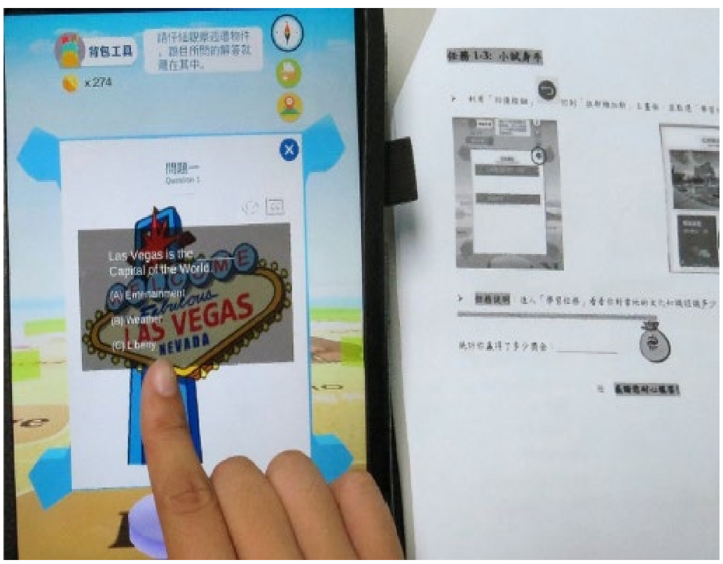


Figure 30. AR with handouts (Chen et al., 2020, p. 13).

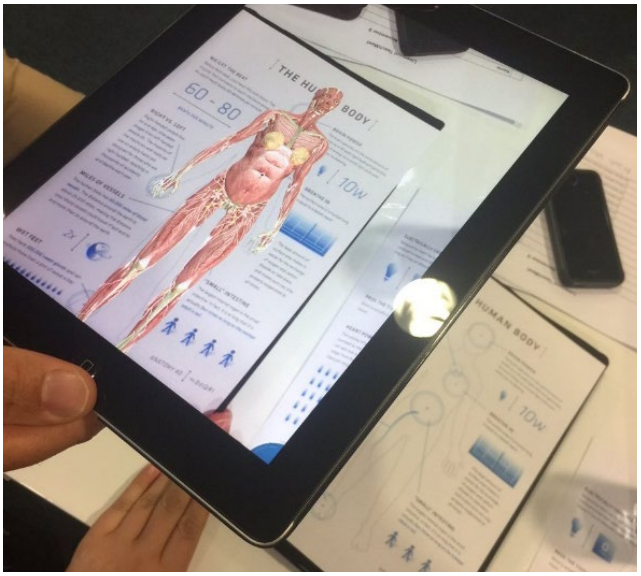


Figure 31. AR with paper-based materials (YSAR, 2016).[12]

A real object can be also used as an AR trigger, as mentioned by Chen (2019). In this study, cupcakes were located in a classroom, and when students scanned the cupcakes with a mobile device, associated virtual objects (i.e., math questions) appeared on the screen (see Figure 32). Lastly, an interactive map (see Figure 33) was utilized in Chen et al.'s (2020) study. The map included various images functioning as triggers for virtual objects. This map was employed as a supplemental material to develop a story for theme-based contextualized learning. Overall, although there are a variety of instructional materials, paper-based handouts are currently the most widely investigated.

[12] Augmented human body anatomy. [Image]. (2016).

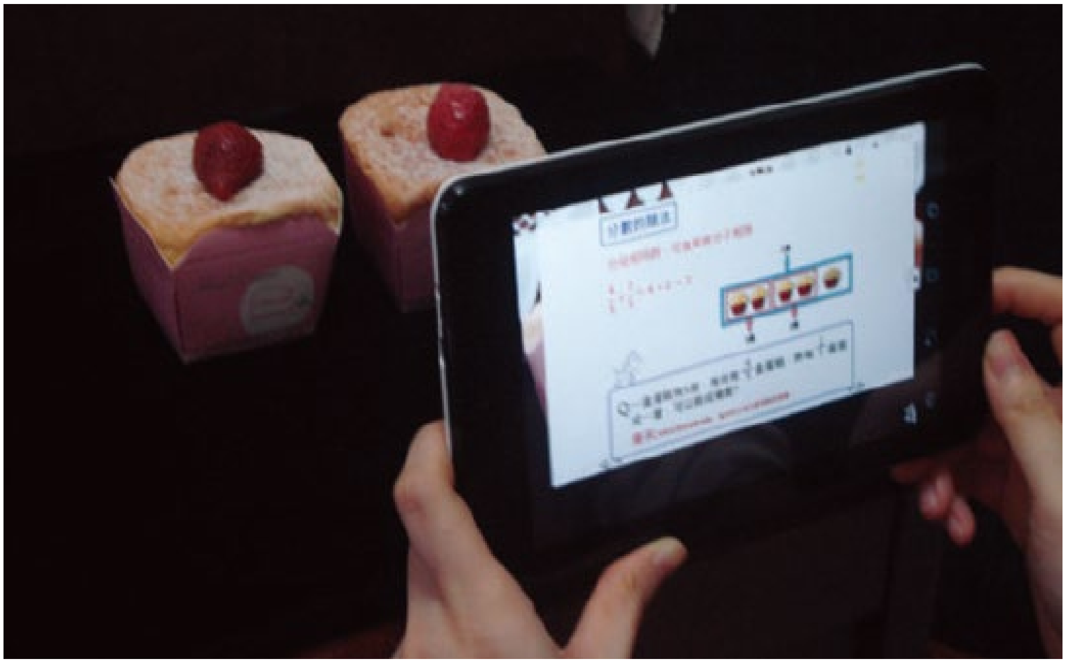
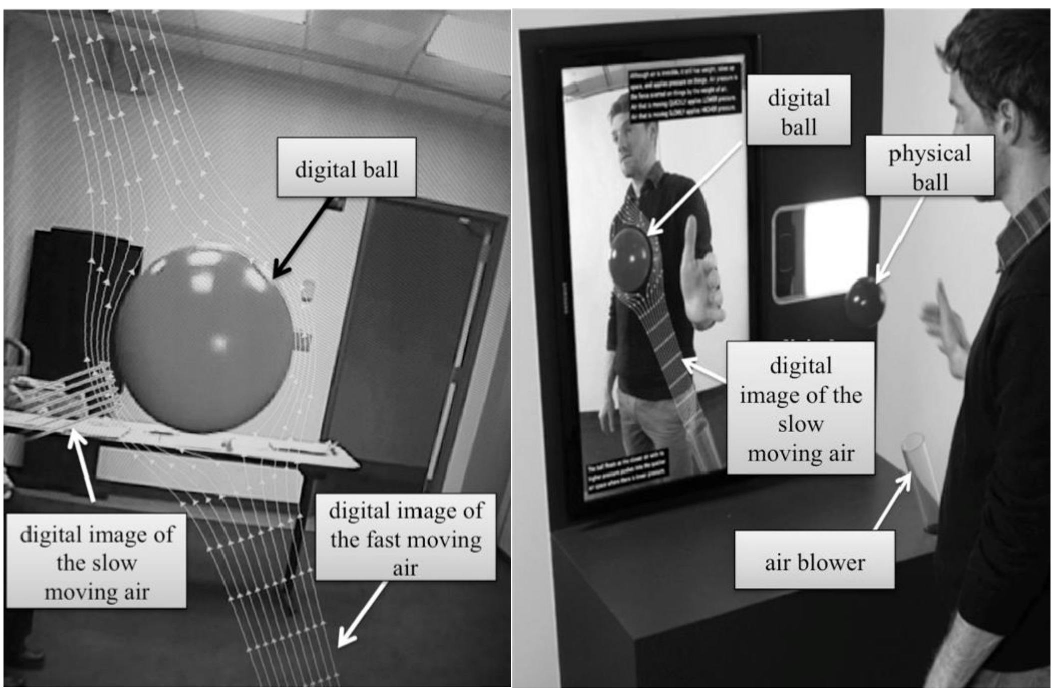


Figure 32. Real objects used as a marker (Chen, 2019, p. 9).

Figure 33. An interactive map (Chen et al., 2020, p. 20)

In terms of the devices used for the AR-based activity, a tablet, smartphone, and Bernoulli blower device, which enables Bernoulli's principles to be applied in a real situation, were employed in the reviewed studies. The most commonly used device was a tablet, which was employed in 11 of 18 studies (about 61%). A smartphone, a similar mobile device, was mentioned in 2 of the 18 studies. These devices are used to scan images and markers as AR triggers, display virtual objects, deliver content, and/or provide learning activities. They are commonly employed because they are the most prevalent and familiar to the public. An unusual device was utilized in the study by Yoon et al. (2017): a Bernoulli blower device located in a museum (see Figure 34). When a student started to operate the device, a ball floated in the air. The device recognized the ball, and 3D visuals were presented on its screen so that the students could interact with the virtual objects.



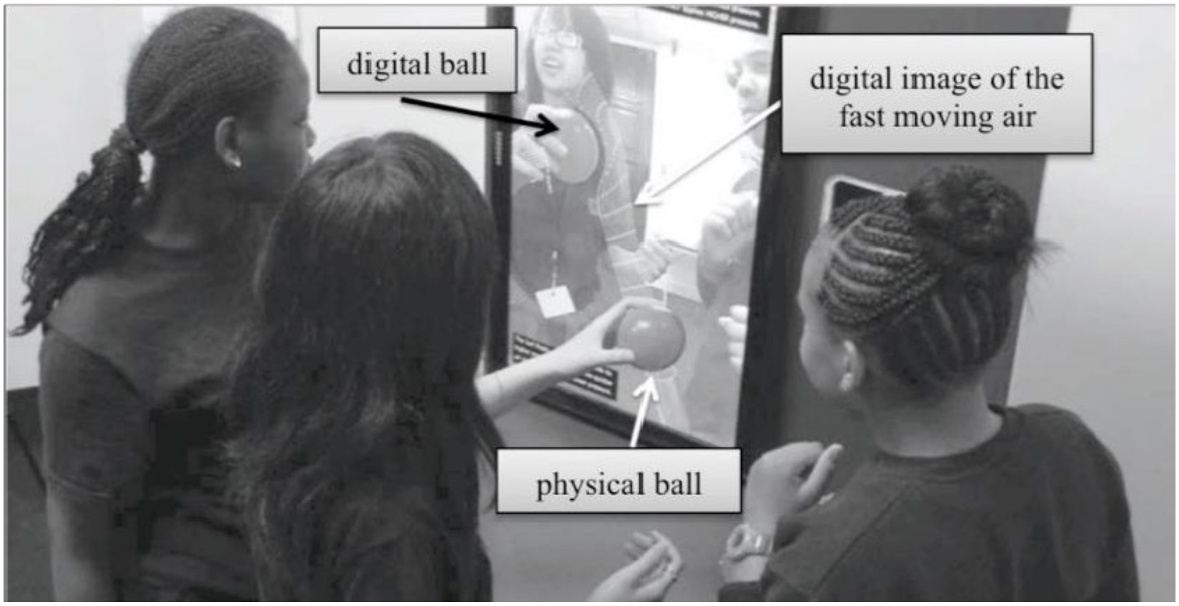


Figure 34. AR device for teaching students about Bernoulli's principle (Yoon et al., 2017, p. 4).

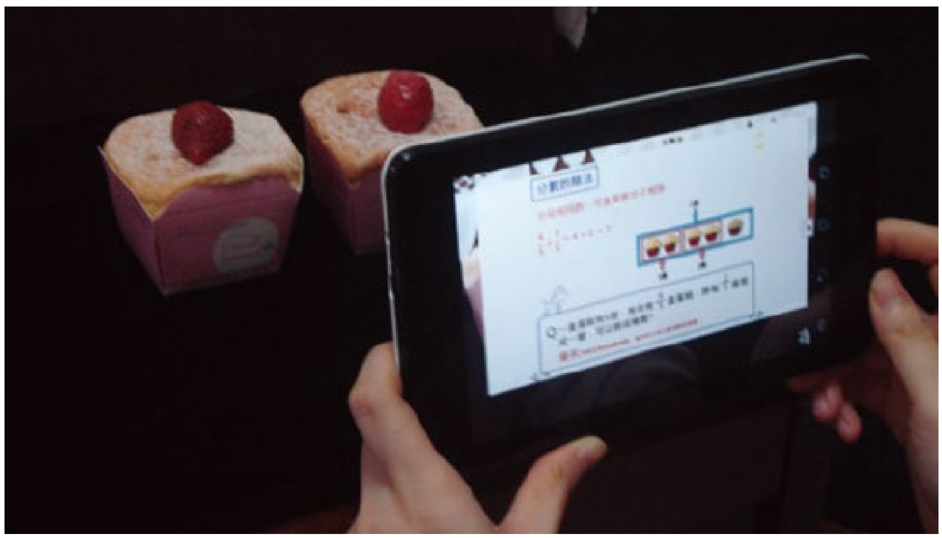
Platform

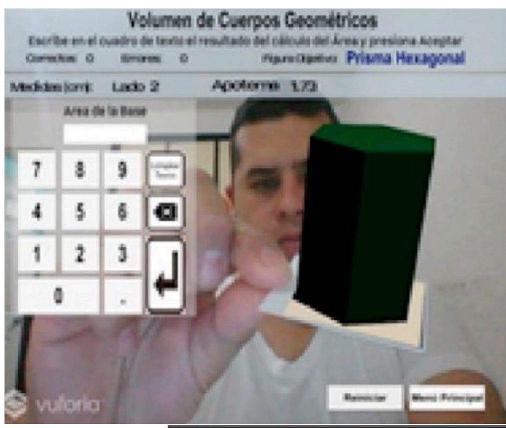
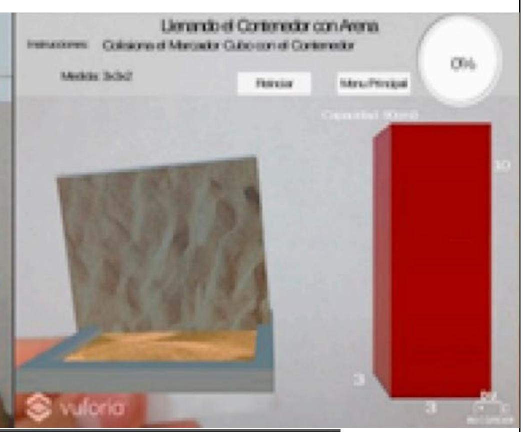
The most popular platforms for all types of AR are iOS and Android. To be specific, 12 of the 18 studies (67 %) reported AR-based learning activities administered through applications. One commonly used device for AR-based activities in middle schools is a tablet PC. With mobile devices like a tablet and smartphone, applications are readily downloadable via the App Store (iOS) and Play Store (Android), and they can be used anywhere with Internet access. The following are the applications utilized in the studies.

Table 3

Examples of AR Applications

Name of the Application	Details
	https://www.augment.com/

Augment	 
FenAR	

	 
ARGeo	Volumen de Cuerpos Geométricos Prisma Hexagonal Lado 2 Apotema 1.73 7 8 9 4 5 6 1 2 3 0 . Reiniciar Menú Principal vuforia Llenando el Contenedor con Arena Reiniciar Menu Principal 0% vuforia Web-Based Learning Geometry Ejercicio 1 Ejercicio 2 Ejercicio 3 Cálculo de área y volumen de prismas regulares. Con base en las medidas que aparecen en pantalla, calcula el área de la base de un prisma regular. Escribe tu respuesta en el bloque de texto y presiona el boton verificar. Una vez calculada el área de la base, aparecerá la medida correspondiente a la altura del prisma, calcula el volumen del prisma regular. Escribe tu respuesta en el bloque de texto y presiona el boton verificar. Figura: Cubo Medidas de un lado: 4 cm Tu respuesta es: Validar

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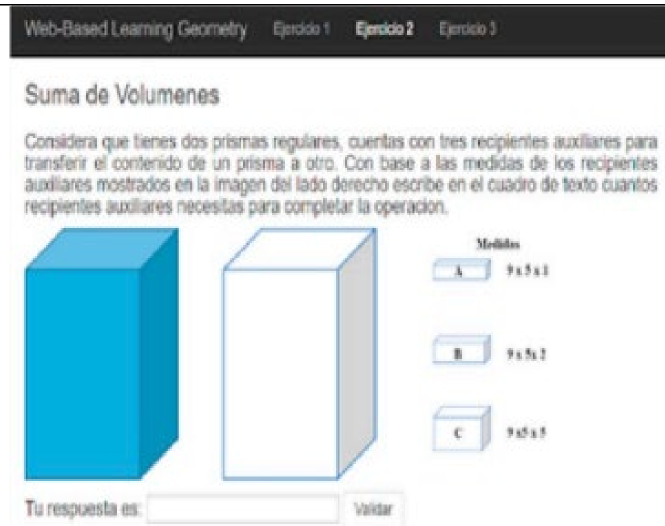

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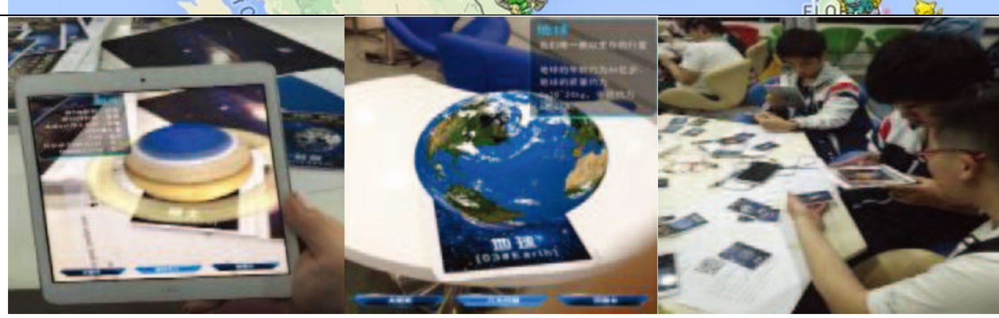
Pokémon GO	CAMERA Growlithe CP 472 Voltorb CP 282 Nidoran♂ CP 210MONTANA NORTH DAKOTA MINNESOTA SOUTH DAKOTA OREGON WYOMING IOWA NEBRASKA ILLINOIS OHIO NEVADA UTAH United States COLORADO KANSAS San Diego NEW MEXICO ARKANSAS Houston
	

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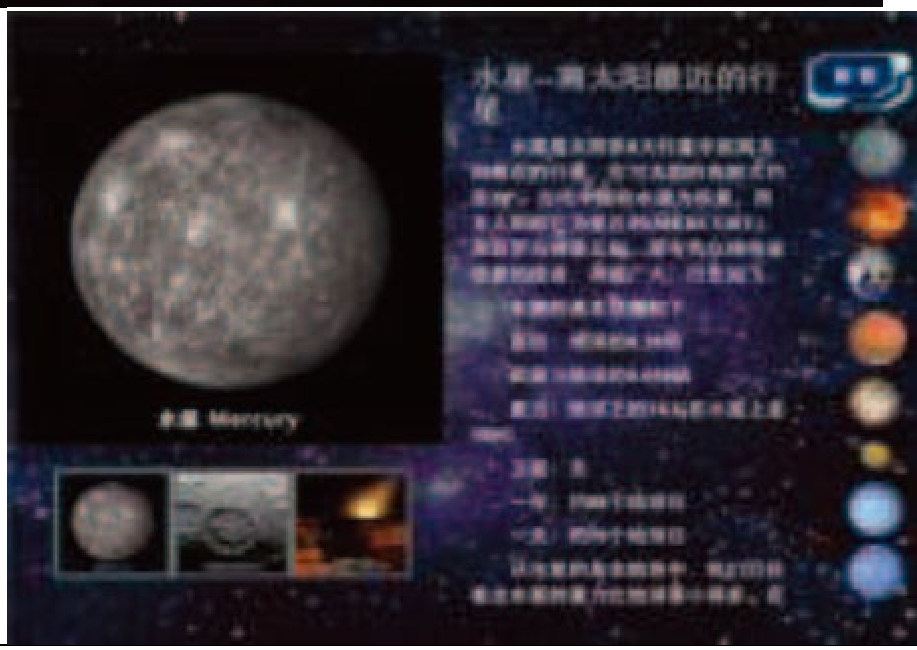

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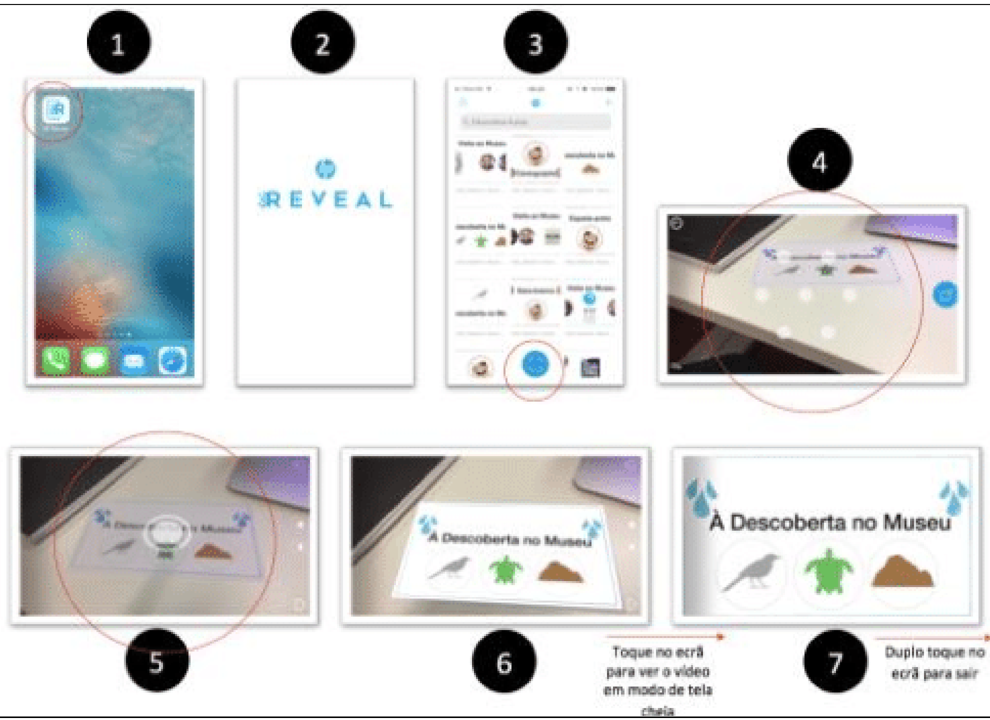
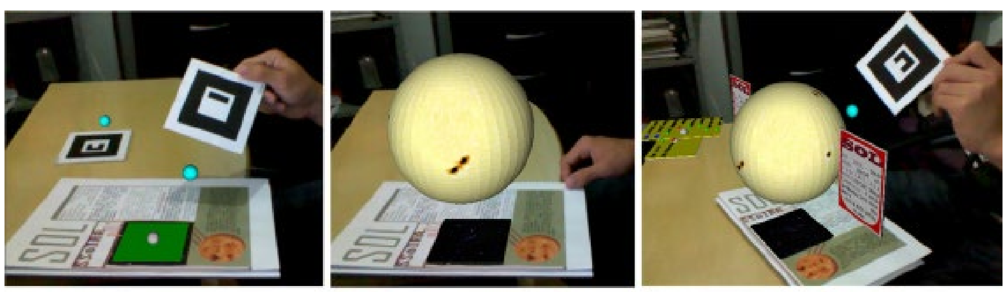
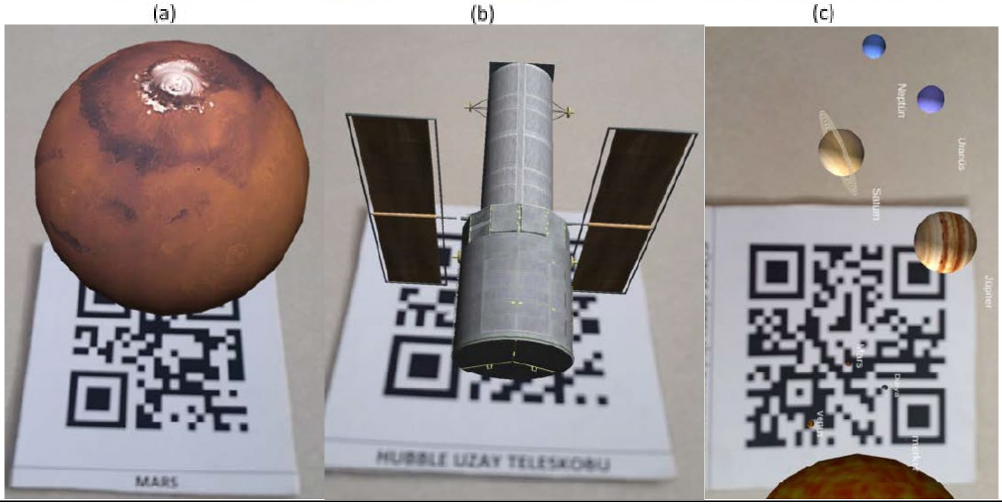
UzayAR	 
HP Reveal	https://www.hpreveal.com/index.html

	
SpaceAR	https://apps.apple.com/us/app/solar-space-ar/id1334422557  (a) (b) (c) 

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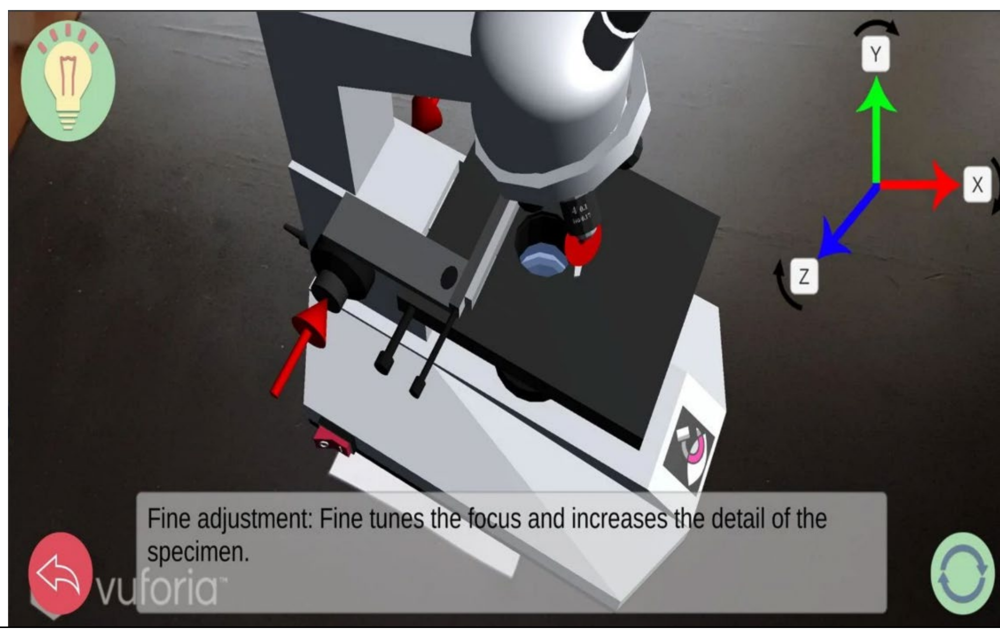
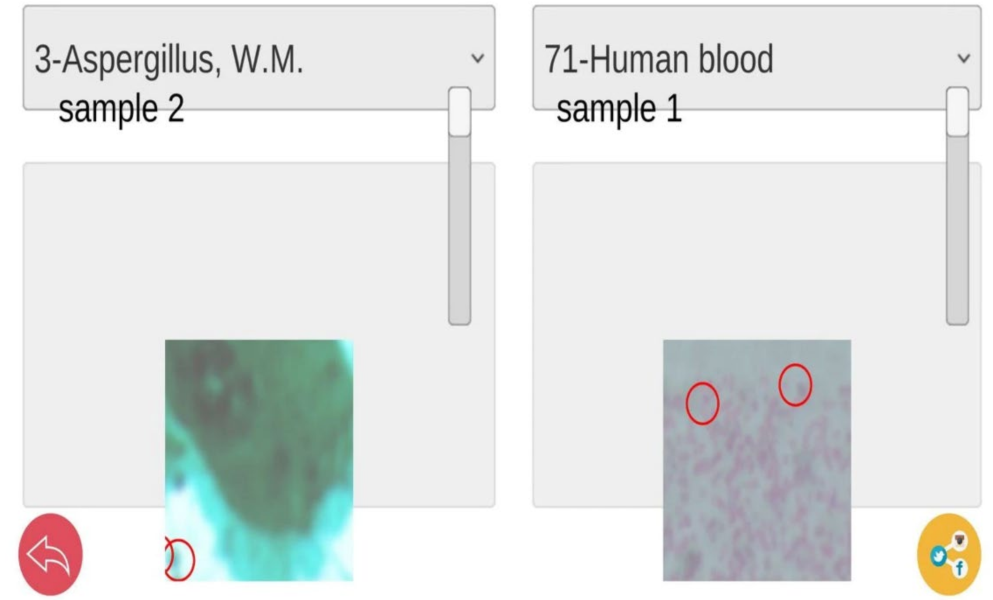
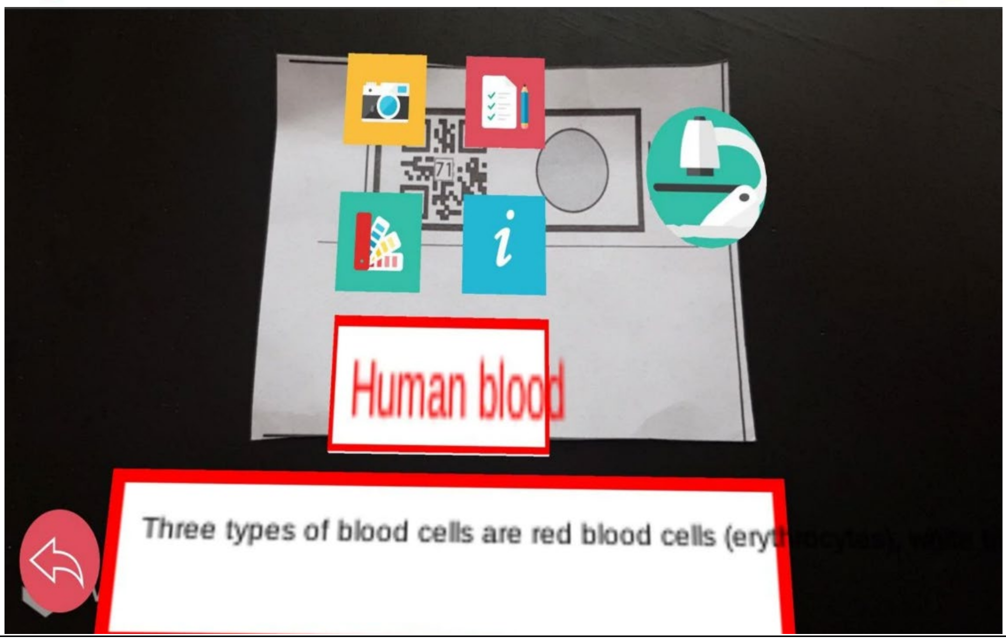
MicrosAR	https://play.google.com/store/apps/details?id=com.arcenter.microsar 

	 3-Aspergillus, W.M. sample 2 71-Human blood sample 1  71 Human blood Three types of blood cells are red blood cells (ery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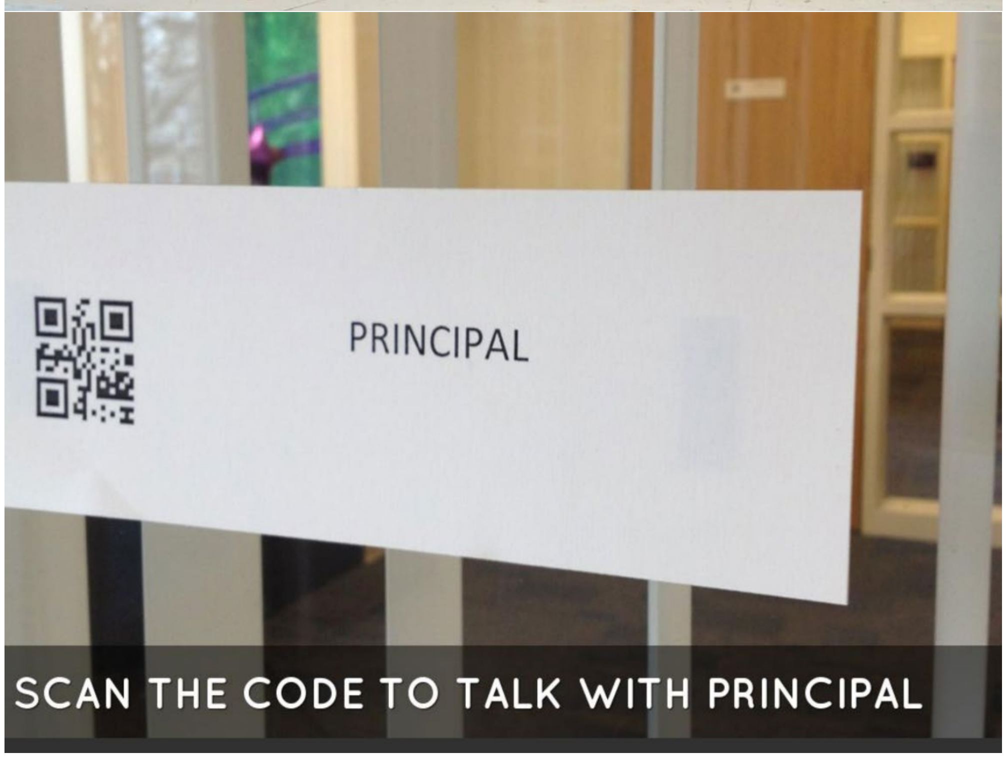

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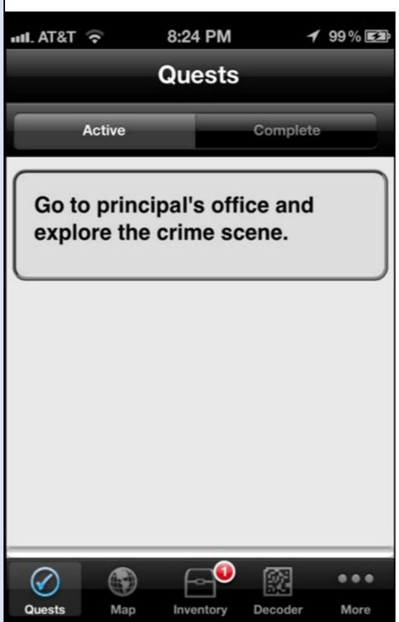
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Map
Inventory
Decoder
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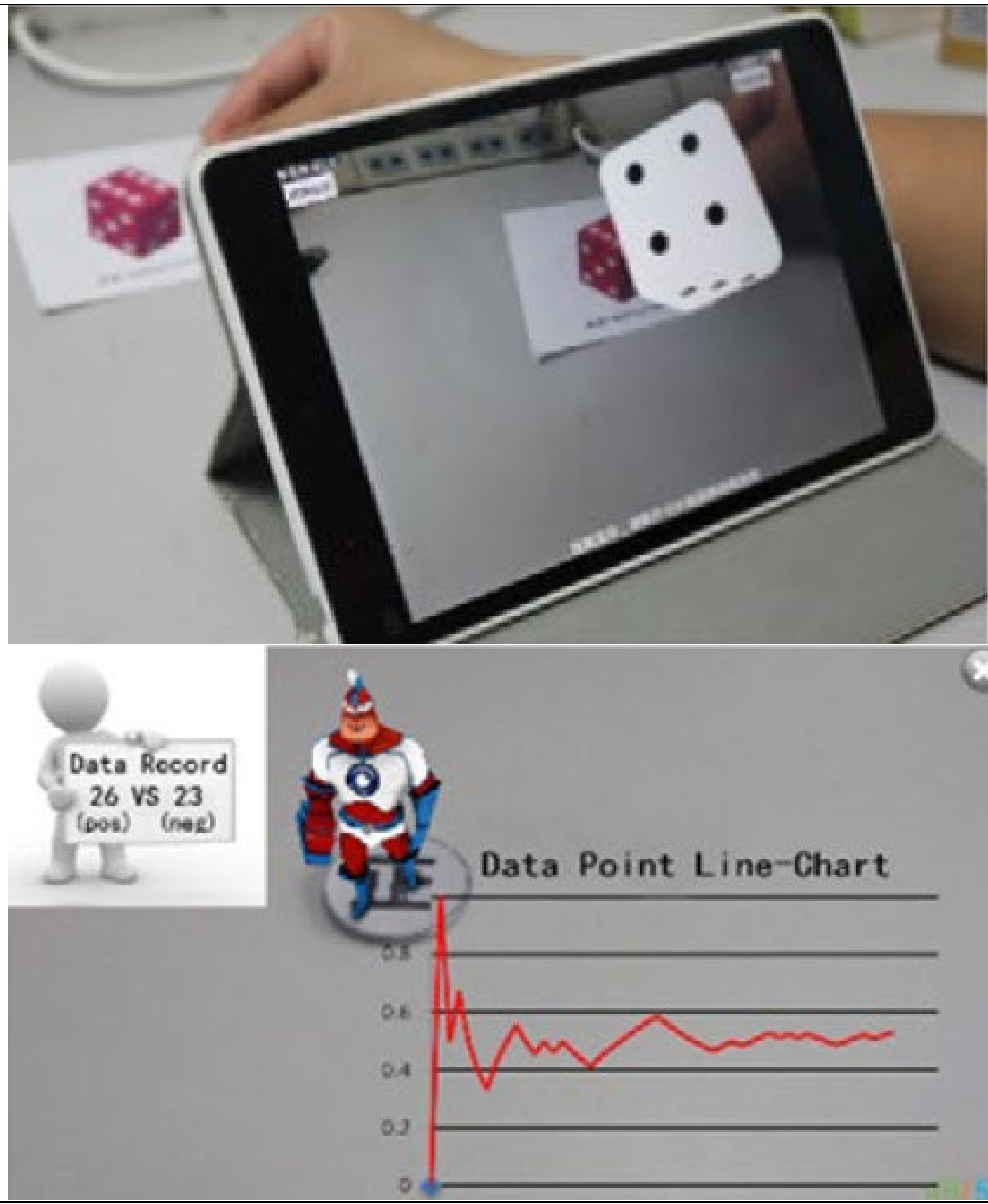
Seven, Super Spaces, and Magic Coins (three applications)	

Another popular platform for AR is game platform. Some applications mentioned in the studies (n = 4) are game-based, which means that there is an ultimate goal to be completed by clearing small challenges. Examples of AR-based game applications are Pokémon GO, MathMon, School Scene Investigators, and Seven. Both types of AR are used in games; Pokémon GO is a location-based AR application, while the other three are marker-based AR applications. Depending on a design of the game, collaboration and/or competition components could be included. For instance, Ruiz-Ariza et al. (2018) developed an application called MathMon, which is an AR-based game application inspired by a treasure hunting game (for its scenario) and Pokémon GO (for the idea that a user wanders around to catch monsters). The goal of the game is for a team consisting of 10 people to catch all 10 hidden math monsters. When a team member scans an image corresponding to a monster, the monster will show up on the screen and the team will need to solve a math problem together. The goal is to successfully complete all the questions assigned to the ten monsters in the shortest possible time. Based on this case, teachers can provide AR-based instructional activities through game platforms. Although there are advantages of such platforms, which will be explained later, it is important for the teacher to select an appropriate AR game application and thoroughly design a lesson plan in order to teach the content effectively based on teachers' needs.

A powerful platform for the implementation of AR is AR authoring tools, which are software programs that allow a user to design, develop, and customize educational AR applications. Kyza and Georgiou (2019) used the AR authoring tool TraceReaders to develop an AR application called Mystery at the Lake. TraceReaders assists in creating location-based AR applications specifically targeting problem/inquiry-based learning. In the authoring tool, users can select a specific location to trigger each virtual object, which may be a 3D object, animation, image, scenario, or video. TraceReaders also enables the user to set which virtual objects are triggered at certain locations by using GPS coordinates and inserting the corresponding content into an AR educational application. This allows students to access superimposed information that is relevant to the specific location in the AR application in situ.

A similar AR authoring tool is ARIS, which is an open-source, web-based AR game design and storytelling platform developed by members of the Mobile Learning Lab at the

University of Wisconsin–Madison (Bressler & Bodzin, 2013). The ARIS platform enables users to create iOS applications to play AR games, take tours, and collect data via a drag and drop mechanism (Holden, 2015). There are two ARIS formats, which are distinguished by whether (a) locations are within ARIS or (b) locations are known in ARIS. The former is used to create location-based AR games using GPS coordinates, and users are required to create a location for a certain virtual object by dragging and dropping the object onto a Google map. It is also possible to create vision-based AR games with the second format. Instead of placing the virtual object on a Google map to make a location in the AR game, users can generate a location by placing a QR code at a certain spot to provide access to information. ARIS is not limited to a particular discipline, subject area, or skill, and there is no one way to develop AR-based games with this tool; it has multiple uses and can be utilized for diverse purposes. However, AR games developed via ARIS can be played only on the iOS platform and cannot be run on the Android system, which is a critical disadvantage of the platform.

SSI, developed by Bressler et al. (2019), is an example of an AR game developed with printable QR codes, school Wi-Fi access, and the free ARIS editor that did not require many preparatory materials. SSI is a scenario-based and vision/marker-based forensic science AR game that uses QR codes to direct student's play. In the game, score sheets are stolen from the principal's room. Learners, as investigators, should collaboratively collect data and find the thief with their team members by scanning QR codes to find clues placed around their school. Collaborative problem-solving skills are required to accomplish the final goal.

CoSpaces Edu and Metaverse are also AR authoring tools. CoSpaces Edu lets teachers and students create their own 3D objects and animate the objects with simple code. Metaverse allows users to create AR interactive content involving texts, objects, and animations. Such tools provide a great deal of freedom to choose options and let users design content that is adaptable to any subject and grade. However, time, effort, and knowledge of pedagogical and technical knowledge/skills are required in order to produce a quality AR application.

Case Study

This section presents a case study conducted by Tomara and Gouscos (2019), who argued that AR mobile learning could be integrated in physics curricula, in order to describe how AR technology was implemented in a middle school classroom. Specifically, the learning objectives for AR content, types of AR, AR application design, AR application implementation, and supplemental materials/devices are discussed.

Subject area and participants. The study examined an AR application integrated into a physics course. This application covered electric forces as well as Coulomb's Law for upper middle school students, who were 14 to 15 years old. A single intervention with the AR application consisted of four 45-minute sessions.

Learning objectives. The learning objectives for the AR learning content designed by the researchers were as follows: "1) Investigate the attractive or repulsive nature of forces between like of opposite charges. 2) Identify the action-reaction interaction between charges. 3) Comprehend the underlying relationships among electric force, quantity of charge, and separation distance" (Tomara & Gouscos, 2019, p. 5).

Types of augmented reality. The study used marker-based AR for learning physics concepts, and two 5 cm × 5 cm pieces of paper with printed images were used as markers. Each piece of paper represents an electric charge. When the printed images were scanned by a mobile camera, the AR application superimposed the electric charges and electric forces on the mobile device's screen.

Augmented reality application design. The authors applied the design requirements proposed by Kerawalla et al. (2006) in order to maximize learning opportunities and maintain students' attention during AR-based activities. The following design requirements were implemented by the researchers:

- Employed no linear structure in order to ensure that the AR application could move from one activity to another and that previous steps could be repeated if needed.
- Provided designed worksheets with instructions to encourage learners to manipulate the overlaid virtual objects and reflect upon the implications of their actions.
- Added collaborative elements by having learners to use handouts and make observations and experiment at their school desks, which are more convenient for gathering and having discussions than desks in a computer lab.
- Visualized intangible concepts (i.e., the magnitude and direction of forces) with 3D virtual arrows in order to promote learners' understanding of force-related concepts.
- Minimized the use of textual directions in the AR interface, which could be disruptive during AR-based learning activities and restricted due to the limited screen size of mobile devices.
- Rather than directly explaining Coulomb's Law (the formula for determining the magnitude of electric force), encouraged students to truly understand and practice the formula step-by-step, following the instructions written in the provided handouts.

Supplemental materials/devices. Two pieces of paper were used as markers, and an Android mobile device for the AR application was needed. Additionally, handouts were given to help students understand and implement a physics formula step by step, following the instructions written in the worksheets.

Implementation of augmented reality application. With the developed AR application, learners could observe virtual electric charges and electric forces (represented by arrows), which are not observable in real life. The learners were also able to see changes in the magnitude and direction of forces as they changed the distance and position of paper cards representing the charges. Moreover, students could interact with the content in real time by receiving numeric data of the actual distance between the augmented electric charges as well as the corresponding force value. Additionally, the learners could experiment by changing the numeric values for the magnitude and type of charge. Therefore, the meaning of the formula can be learned step by step by manipulating the virtual objects and digital information.

The following are descriptions of how each session in the study was conducted. In the first session, since it was the learners' first time using the AR application in a physics class, the researchers faced problems regarding the application's compatibility and selection of the most suitable device for the AR application in terms of screen size and camera resolution. In addition, the researchers explained to the students how to use the AR interface.

During the second and third sessions, the learners played with the AR application and observed and examined the relationships between variables by changing numeric values and moving markers. In order to use the limited time effectively, the students were assigned each role during the AR-based learning activities. Tomara and Gouscos (2019, p. 10) mentioned that:

> As part of the group, each student has been assigned a role: one targeting the mobile device to the frame markers, one mobbing around the markers and the third (the third and the fourth in the case of the four-student group) reading instructions and filling tin the worksheet guiding the intervention. The students changed roles after one or two worksheet tasks have been completed.

For the last session, assessments were conducted. Specifically, a questionnaire was administered to collect students' feedback and measure their attitude toward the course with the AR application.

Part II: Practitioner Report

The following is a practical article developed for submission to the journal of the ATPE. It will be submitted for the Fall 2020 edition.

Augmented Reality: A Promising Technology in Education

With AR technology, educators can create novel, interactive experiences for learners. In a classroom that includes AR, students hold a mobile device and look at the digital content displayed on the screen, observing phenomena they cannot see in daily life, such as organs inside the human body (see Figure 35) and the structure of the Earth. Students are drawn to the realistic 3D graphics offered by AR and are interested in the learning activities. They actively interact with the content by touching, zooming in/out, and dragging digital objects shown on the screen, and they interact with other learners and the teacher to discuss content-related topics.

Figure 35. Example of AR in the classroom (The Code Show, 2018).[13]

What is Augmented Reality?

AR is a technology that enhances a user's visualization of the physical world by layering multimodal digital information, such as 3D objects, graphics, animations, and videos, on the

[13] Virtuali tee in classroom [Photograph]. (2018).

physical environment in real time through a digital device. The digital content is referred to as virtual objects. These objects synchronously interact with the real world, constantly updating as the real world changes. For instance, as a learner touches or zooms in on a virtual heart or lung, in AR, they can view each organ's name and see how they work in real time. Moreover, in the AR-based application Virtuali-Tee, AR technology shows the learner's heart rate on their body in real time. In this way, AR technology can provide additional and contextual information that cannot be experienced otherwise.

There are two types of AR that differ in terms of how the technology triggers virtual objects. In marker/vision-based AR, the camera of a mobile device is used to trigger specially designed markers, such as QR codes or 2D targets (see Figure 36). After scanning these markers, virtual information is layered on the mobile device's screen. Cai et al. (2017) described a case in which students were involved in learning by using an AR-based application activated by QR codes: School Scene Investigators: The Case of the Stolen Score Sheets. In this AR-based forensic science game, upon scanning a QR code with a smartphone, a window popped up and provided either information or instructions for a learning activity (see Figures 37, 38, and 39). Then, students could continue playing and complete the game.

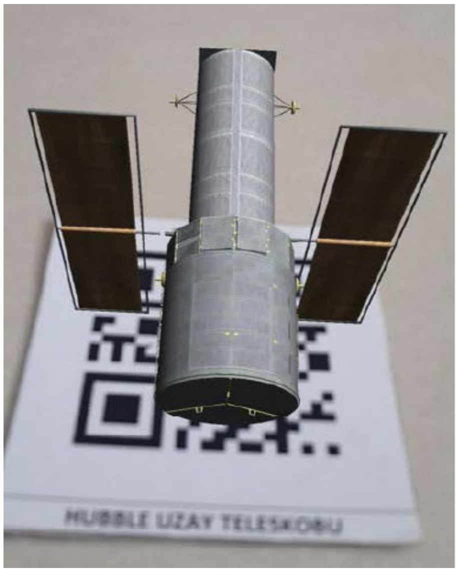


Figure 36. QR code (Sirakaya & Çakmak, 2018, p. 6).

Figure 37. Example of a quest in School Scene Investigators: The Case of the Stolen Score Sheets (Holden, 2015, p. 91).

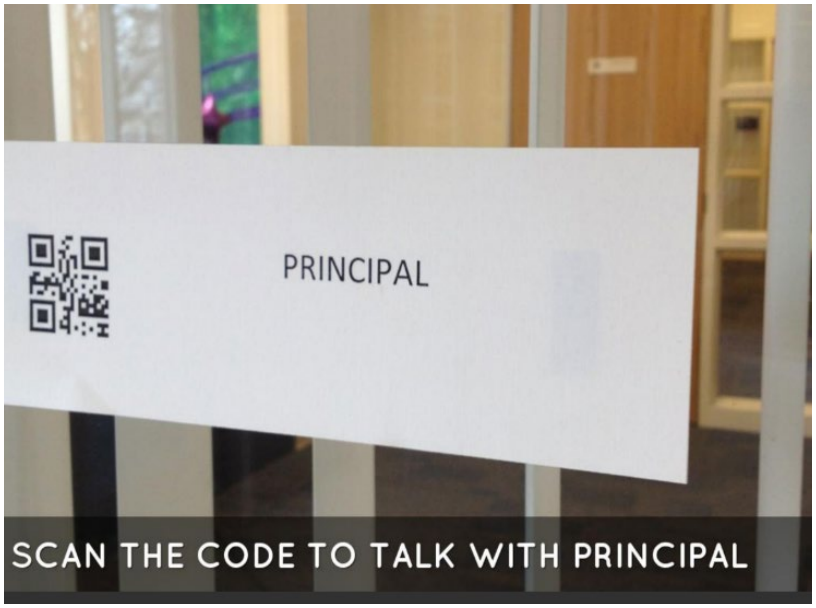


Figure 38. Second example of a QR code in School Scene Investigators: The Case of the Stolen Score Sheets (Holden, 2015, p. 91).

Figure 39. Students playing School Scene Investigators: The Case of the Stolen Score Sheets (Holden, 2015, p. 94).

In contrast, in location-based AR, virtual information is pre-programmed to appear at specific physical locations. When a user and their GPS-enabled mobile device are near enough to the location, digital content appears on their screen. One example of such an application is Mystery at the Lake (see Figure 40), in which a student is given a mission to solve the mysterious decline of the lake's mallard ducks. During the learning activity, the student investigator wanders around a real lake with a tablet in order to obtain information through AR videos and text-based information at certain physical locations. By engaging in the learning activity and solving the problem, students gained much knowledge about the ecosystem. However, location-based AR requires teachers to set up the location-based targets before running the learning activities.

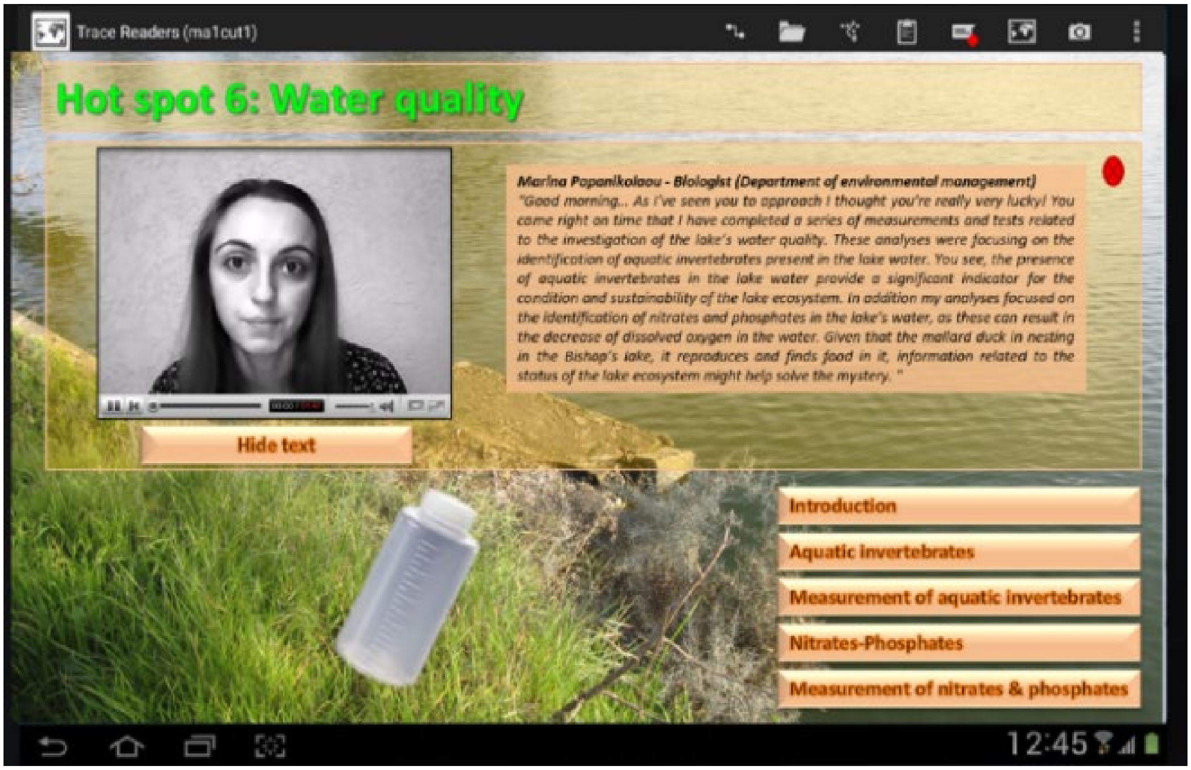


Figure 40. Screenshots of Mystery at the Lake (Georgiou & Kyza, 2018, p. 3 & 5).

What are the Features of Augmented Reality?

AR technology has several features. The following are commonly mentioned features.

Real-Time Interaction and Manipulation

Virtual objects in AR react as a learner manipulates them or as the physical environment changes. As a result, the learner can receive real-time feedback when interacting with unfamiliar concepts and test their knowledge by manipulating simulated objects, possibly enhancing their comprehension. Figures 41 and 42 show an example in which AR technology is used to quiz students about butterfly anatomy. The students can select the topic they want to address by touching its name. By tapping on and placing an arrow pointing to the butterfly's body parts, they can check their knowledge.

Figure 41. Quiz about butterfly anatomy embedded in an AR application and the topics it covers (Bhagat et al., 2019, p. 6).

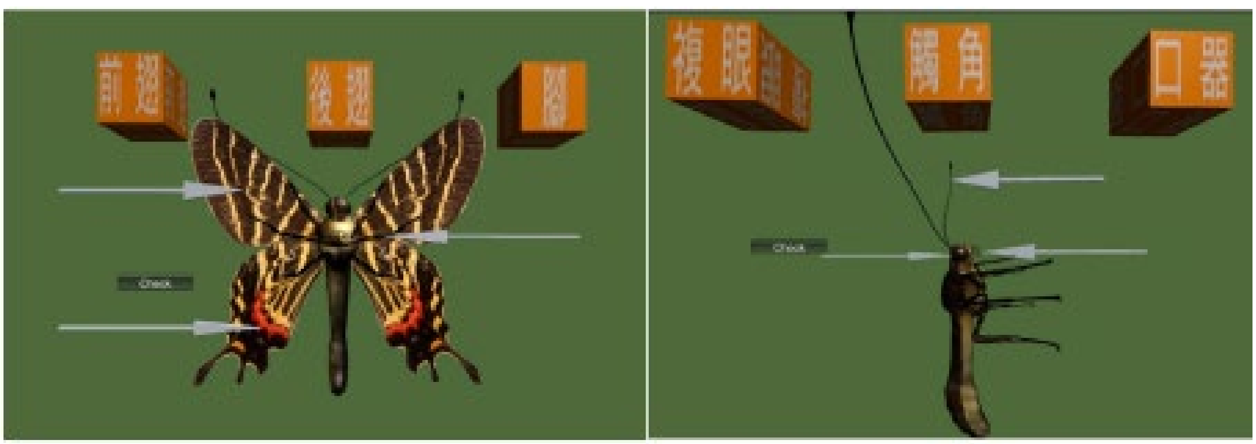


Figure 42. Example questions about butterfly anatomy (Bhagat et al., 2019, p. 6).

Realistic/3D Visualization

AR supports highly realistic visualization and 3D objects. Such objects have not only length, width, and height but also depth and thickness, similar to how humans perceive the physical world. Thus, AR technology offers sharp, realistic visual materials, which could catch learners' attention, promote understanding, and prevent misconceptions. For instance, an AR application called SpaceAR allows students to easily visualize Mars and the solar system with QR codes (see Figure 43).

Figure 43. 3D visualizations in an AR application (Sirakaya & Çakmak, 2018, p. 6).

Multimedia/Multimodal Content

Digital information includes multimedia and multimodal learning materials, which may be 2D or 3D and either visual or acoustic in nature (see Figure 44). These learning materials can make content much more comprehensible and supplement learners' sensory perceptions of the real world.

Figure 44. Multimedia/multimodal content provided by AR (Chen et al., 2020, p. 13).

How Can Augmented Reality Benefit Classroom Learning?

Many studies have reported the affordances and numerous positive effects of AR on learning outcomes. AR has been shown to enhance three learning outcomes: knowledge/understanding, skill-building, and learner engagement.

Knowledge/Understanding

Many studies reported improved content comprehension and academic achievement upon implementation of AR. Students using AR technology actively interacted with content and achieved higher academic performance compared with students who used web-based lessons or traditional learning methods. Moreover, AR affected both the students' immediate learning and their retention over the course of the study. In another study, AR minimized learners' misunderstanding of intangible concepts due to the affordances of AR, particularly the ability for concretization of abstract concepts and invisible objects and real-time interactions (Yoon et al., 2017).

Building of Collaboration, Analysis, and Problem-Solving Skills

As learners work together as a group, they can improve their collaboration skills by interacting with group members and cooperatively achieving a shared goal during AR-based learning activities (Yoon et al., 2017). Moreover, according to studies focusing on AR as a learning technology, it can enhance learners' scientific process and analytical skills (Abdusselam & Kilis, 2018) as well as their problem-solving skills. During a learning activity like an AR-based game, problems or missions are provided to students. In order to determine the correct answers, they need to think step by step and test each hypothesis by analyzing the problems and comparing potential solutions (Fidan & Tuncel, 2019). Consequently, AR could provide opportunities to strengthen those skills.

Learner Engagement

Because of the realistic visualization and real-time interaction, AR can easily draw students' attention. Thus, it is more likely that students will be immersed, motivated, and engaged in learning activities with AR-based materials. The features of AR also make learning content interesting to students, making them inclined to actively participate in learning and interact with content as well as making it easier for them to easily comprehend content. As a result, students' anxiety about a certain topic and/or subject area may be diminished (Chen, 2019). Positive learning experiences with AR technology promote optimistic attitudes toward learning and the subject domain.

How to Implement Augmented Reality in the Classroom?

Four guidelines for teachers who aim to effectively implement AR in the classroom are proposed:

1. **Analyze the learning content**: Before selecting an AR tool, analyze the learning content. Examine whether the learning activities deliver content or call upon learners to ensure that a suitable AR application is chosen. For instance, when learning activities are focused on delivering intensive content, AR technology that enables information to be provided with superimposed multimedia would be much more appropriate than an AR-based game.
2. **Check available classroom technology tools**: While planning AR-based learning activities, it is important to check which technology tools are ready to use in the classroom and which tools the teacher can obtain for the classroom in which the AR technology will be integrated. Specifically, consider how many mobile devices (e.g., tablets and smartphones) the teacher can obtain and whether the school can afford to buy a new toolkit for an AR-based application. This can determine which learning activities should be conducted with AR technology.
3. **Thoroughly plan a lesson by playing with the AR technology**: In order to comprehensively plan a lesson, teachers are encouraged to play with the AR tool that the students will use. This will allow the teachers to view the planned lesson from students' perspective and prepare for unexpected situations. Additionally, teachers could plan ahead and prepare with all the necessary materials, such as handouts, QR codes, a toolkit, and the appropriate number of mobile devices.
4. **Have an orientation session to explain how to use an AR tool**: Before the actual lesson, provide students an orientation to the AR tools. This will reduce cognitive

overload of learning AR technology, while also engaging in a lesson, which may overwhelm learners.

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